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# ETROCHEMICAL CRITERIA ESTABLISHING THE RELATION BETWEEN MINERALIZATION AND GRANITOIDS (AS EXEMPLIFIED IN THE MYAO CHANSKIY REGION)[1]

by
M. G. Rub, V. V. Onikhimovskiy, and B. V. Makeyev

Studies of the geochemical characteristics the Upper-Cretaceous intrusions and the companying post-magmatic formations in e Myao-Chanskiy region (Khabarovsk Kray) oduced some interesting new material which nfirms the opinion we expressed in 1956 re- rding the considerable importance of the trochemical criteria associated with the lationship between mineralization and in- usions. In addition, these investigations confirmed the existence of specialized in- usions and showed that intrusive bodies em- aced at different times (the tin-bearing variety, particular) and located in different struc- ral zones may — along with other common atures — also possess certain specific in- vidual peculiarities. Our new material partially described in this article.

## Brief Geological Outline of the Myao-Chanskiy Region

According to I. Ya. Zinter, V. V. Onikhimov- iy, P. A. Epov, and other investigators, the ineralized zone in the Myao-Chanskiy region confined to the zone of Cretaceous folding. omposed of Jurassic rocks and unconformably erlain by Lower-Cretaceous formations, is zone is covered by Upper Cretaceous, eogene, and Early Quaternary effusives.

The principal structural feature in this gion is a major anticline (the Badzhalskiy anticline) which strikes in a north easterly rection. The center of the geanticline con- sts of Jurassic rocks represented by sand- ones and siltstones with intercalated cherty- ay shales and argillaceous slate, with oc- asional gravels and fine pebble conglomerates. he total thickness of the Jurassic formations 3500 m. They are overlain by Lower Cre- ceous sandstones, siltstones, clay shales and onglomerates containing beds of quartz por- yries, their tuffs, gritstones, tufogenic andstones and tuffites containing fossilized ower Cretaceous flora. According to the data of P. A. Epov, V. V. Onikhimovskiy and other investigators, the Lower Cretaceous formations attain a thickness of 4000 meters.

The Upper Cretaceous deposits, which are well developed in the investigated region (Fig. 1), are represented by a variety of porphyrites and their tuffs comprising the Amutskaya series. The observed thickness of the Upper Cretaceous formations, whose ages were determined from fossil flora is 550 meters.

In addition to these Jurassic and Cretaceous formations, there are extensive Tertiary and Quaternary rocks in the Myao-Chanskiy region of these, only the basalts and dolerites are extensive.

The data of V. V. Onikhimovskiy and others indicate that the structure of the Myao-Chanskiy region is the result of Variscian, Cretaceous, and Cenozoic tectonic stresses. Therefore, the history of its development is long and complex.

## Brief Geologic, Petrographic, and Geochemical Characterization of the Intrusive Rocks

Intrusives are widespread in the Myao-Chanskiy region and consist of gabbro-diorites, quartz-diorites, diorite-monzonites, monzonites, granodiorites, various granites, and other varieties. In addition, this area abounds in dikes of acid (fine-grained granites, aplites, granite-porphyries, quartz-porphyries, felsites), average (granodiorite-porphyries, monzonite-porphyries, diorite-porphyries) and basic (diabasic porphyries, gabbro-diabases) varieties.

All of these intrusives cut the Jurassic and Cretaceous sedimentary deposits as well as the Lower and Upper Cretaceous effusive formations. Thus, the lower age limit of these intrusives is clearly Upper Cretaceous. Their upper age limit has not been precisely determined. The only known fact is that these rocks are overlain by Neogene dolerites and basalts. An absolute age determination of these intrusives made at the All-Union Geological Scientific-

[1] Petrogeokhimicheskiye kriterii svyazi orudeneniya s granitoidami (na primere Myao-Chanskogo rayona). pp. 3 - 23.

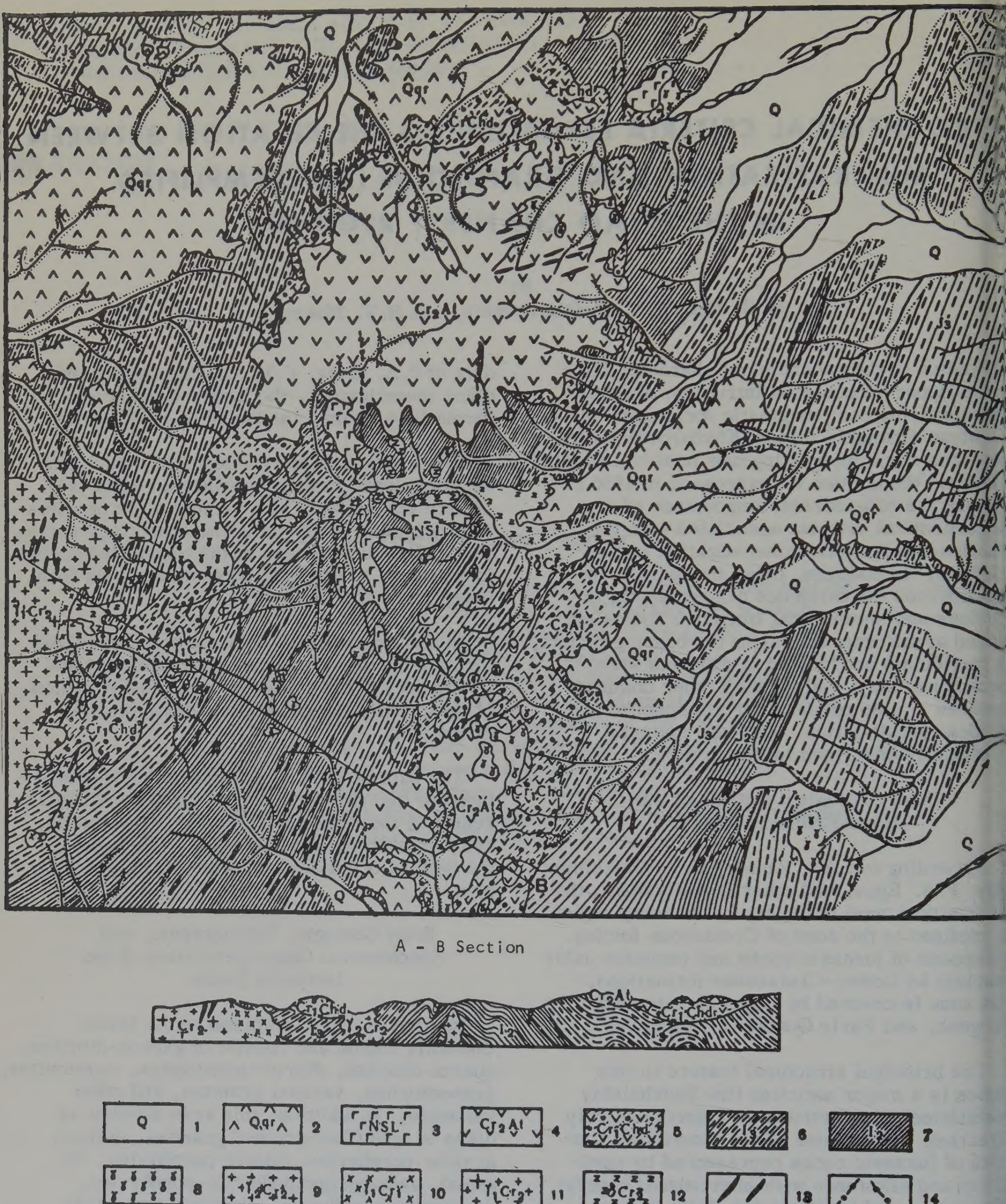


FIGURE 1. Schematic geologic map of the Myao-Chanskiy region compiled by V.V. Onikhimovskiy, et al.

Quaternary System: 1 - alluvial deposits; 2 - basalts, dolerites, and their tuffs. Tertiary System: 3 - dolerites, basalts and their tuffs; pebble-beds, clays, sandy loams, lignites. Cretaceous System: 4 - porphyrites and their tuffs; 5 - conglomerates with beds of quartz-porphyries. Jurassic System: 6 - clay shales, siltstones with interbedded sandstones; 7 - fine- and medium-grained sandstones with intercalations of clay and cherty shales; Myao-Chanskiy intrusive complex granitoids; 8 - non-articulated granitoids of Myao-Chanskiy

Explanation for FIGURE 1 continued on next page.

rusive complex; 9 - porphyritic biotite and alaskite granites, the third phase of the o-Chanskiy intrusive complex. Upper Cretaceous granitoids of the Myao-Chanskiy intrusive plex; 10 - granitoids, quartz-diorites, diorites, facies of endomorphic granites of the ond phase; 11 - biotite and biotite-hornblende granites, second phase of the Myao-Chanskiy rusive complex; 12 - gabbro-diorites, diorites, diorite-monzonites, monzonites, quartz-zonites, granodiorites and other varieties, the first phase of the Myao-Chanskiy intrusive plex. Dikes of the Upper Cretaceous intrusive complex; 13 - Dikes of acid, average, and ic composition; 14 - Fracture zones containing quartz-tourmaline mineralization.

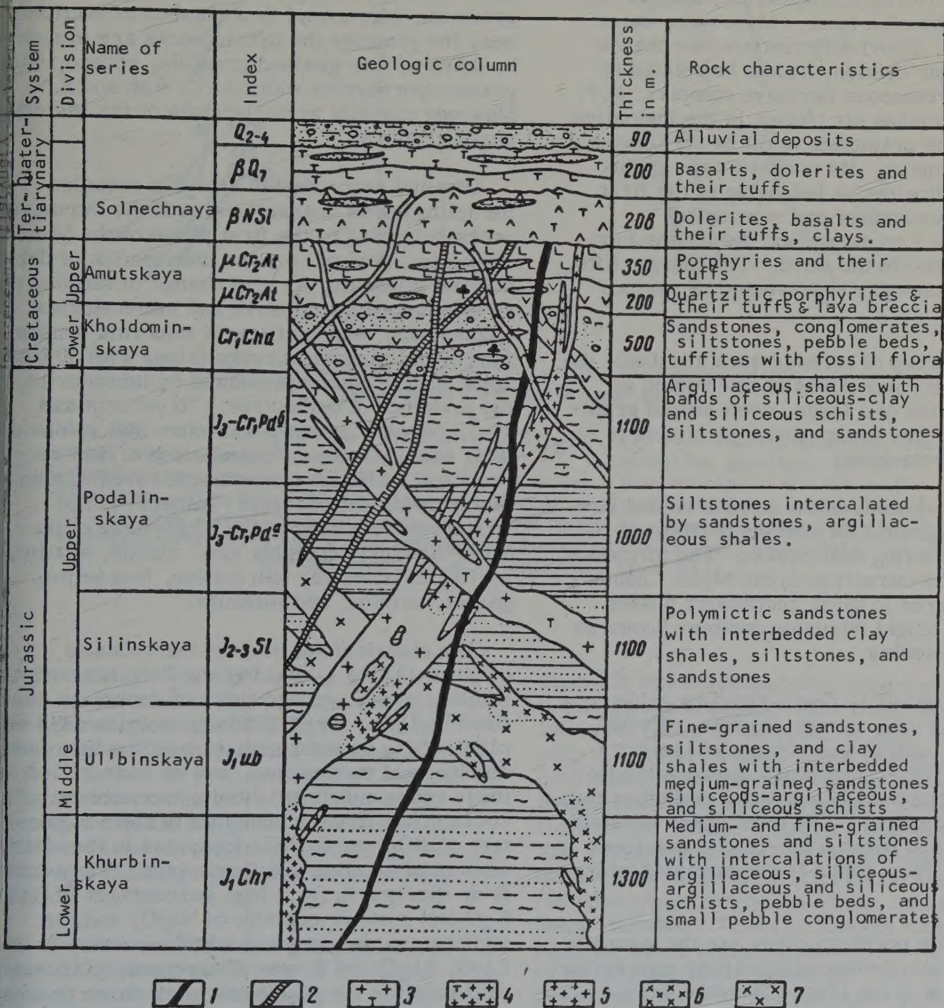


FIGURE 2. Stratigraphic Column

1 - diabase porphyrites; 2 - diorite porphyrites, diorite-monzonite-porphyries, granodiorite-porphyries; 3 - porphyritic, biotite, alaskit tourmaline-bearing granites, third phase of the Myao-Chanskiy intrusive complex, 4 - granodiorites, quartz-diorites, granodiorite-porphyries, marginal phase of the second-phase granites; 5 - biotite and biotite-hornblende granites, second phase of the Myao-Chanskiy intrusive complex; 6 - porphyritic diorite-monzonites, diorite-monzonite-porphyries, diorite porphyrites, marginal phase of the first-phase hybrid rocks; 7 - diorite-monzonites, quartz-diorites, and other varieties, the first phase of the Myao-Chanskiy intrusive complex.

Research Institute (VSEGEI) by N.I. Polevaya using the argon method produced a figure of 80 to 100 million years which corresponds to the Upper Cretaceous. In speaking of the age and of the correlation of the described rocks, one should mention the fact that the views of earlier investigators diverge considerably in this respect. I. Ya. Zinter, E.P. Izokh, O.N. Kabakov, and P.A. Epov, for example, belive that the formation of the intrusives in the Myao-Chanskiy region occurred in several different age-phases. The first to intrude were the rocks of basic and average composition, and the acid rocks were intruded later. Moreover, some authors (P.A. Epov) differentiate two phases which, in their opinion, should be related to the Upper Cretaceous intrusive complex. E.P. Izokh distinguishes six phases in the formative process of the granitoids in the Myao-Chanskiy intrusive complex. He considers the gabbro and gabbro-diorites as belonging to the first phase, the monzonites and monzonite-granodiorites - to the second phase, the monzonite-granites-to the third. The fourth, fifth, and sixth phases are represented by various granites.

Another group of investigators attributes the diversity of the intrusives in this region to facies varieties of a large, deep-seated granitoid mass. They assign these granitoids to the Upper Cretaceous.

Our special study of the intrusives and related postmagmatic formations permits us to make the following assumption. The formation of the various intrusives in the Myao-Chanskiy region occurred in three successive phases related to a single intrusive complex known as the Myao-Chanskiy.

The first phase is represented by gabbor-diorites, diorites, quartz-diorites, diorite-monzonites, quartz-monzonites and other varieties. The second phase includes biotite and biotite-hornblende granites, granodiorites, and quartz-diorites. The third phase consists of alaskitic and porphyritic-biotite granites (Figure 2). Each phase is accompanied by its dike series.

The diorite porphyry dikes are the youngest manifestations of magmatic activity completing the formation of the Myao-Chanskiy intrusive complex.[2]

The first phase intrusives are widely distributed in the basin of Silinka and Kholdomi Rivers where they form a number of massifs covering an area of from 1-2 to 30-40 square kilometers. They are accompanied by their associated dike series represented by diorite-porphyries, diorite-monzonite-porphyries, monzonite-porphyries, granodiorite-porphyries, and other varieties.

An intersection of first-phase hybrid rocks by second-phase granites was observed on the right bank of Silinka River by M.G. Rub and B.V. Makeyev. Potassic metasomatism is observed in the hybrid rocks at the contact with the granites. Moreover, in a number of sections near the granites the hybrid rocks are intruded by dikes of fine-grained granites, aplites, and granite-porphyries which M.G. Rub and B.V. Makeyev classify as derivatives of the second-phase granites.

Detailed petrographic analysis revealed the following as characteristic of the intrusive rocks belonging to the first phase of the Myao-Chanskiy complex: uneven distribution of dark-colored minerals, a rapid change of structures, an unbalanced quantitative and mineralogical composition, associations of minerals unusual for normal magmatic rocks (along with 40% of zonal plagioclase represented by labradorite, the presence of orthoclase - 30 percent and 10-15 percent quartz), and other indications of their hybrid origin. Examination of thin sections and artificial concentrates revealed that the predominant accessory mineral in the intrusives belonging to the first phase of the Myao-Chanskiy complex are: zircon, apatite, pyrite, cassiterite, tourmaline, magnetite, garnet, orthite, and ilmenite.

The chemical analyses of the rocks in question (Table 1, and Figure 3) do not correspond to the average types of rocks, as defined by Daly. In particular, samples c443 and c188 occupy an intermediate position between diorites and monzonites, and we have called these rocks quartzitic diorite-monzonites. The rocks differ from monzonites in their high content of $SIO_2$ and ferrous iron, and in the small amount of alkaline and ferric iron. They differ from diorites in their high percentages of $SiO_2$, $K_2O$ and smaller quantity of $Na_2O$, and, in addition, in the presence of minor amounts of $Li_2O$, $Rb_2O$ and B - the characterisitc accessory minerals for the granitoids of all three phases of the complex. Numerous spectral analyses bear evident to the fact that the usual secondary elements of the described rocks are: barium, strontium, lithium, rubidium, zirconium, boron, lead, copper, chromium, nickel, and cobalt. Thus, the hybrid rocks referred to above contain, on the one hand, a number of elements characteristic for granites belonging to the later phases of this complex (barium, strontium, zirconium, boron, and silicon), and on the other hand, those typical for basic rocks (phosphorous, chromium, nickel and cobalt).

[2]V.V. Onikhimovskiy believes that it is possible to differentiate three interrelated groups among other intrusive rocks. Of these, the first and the second (which correspond to our first and second phases) are usually spatially separated, whereas the third represents the final and residual derivatives of granites.

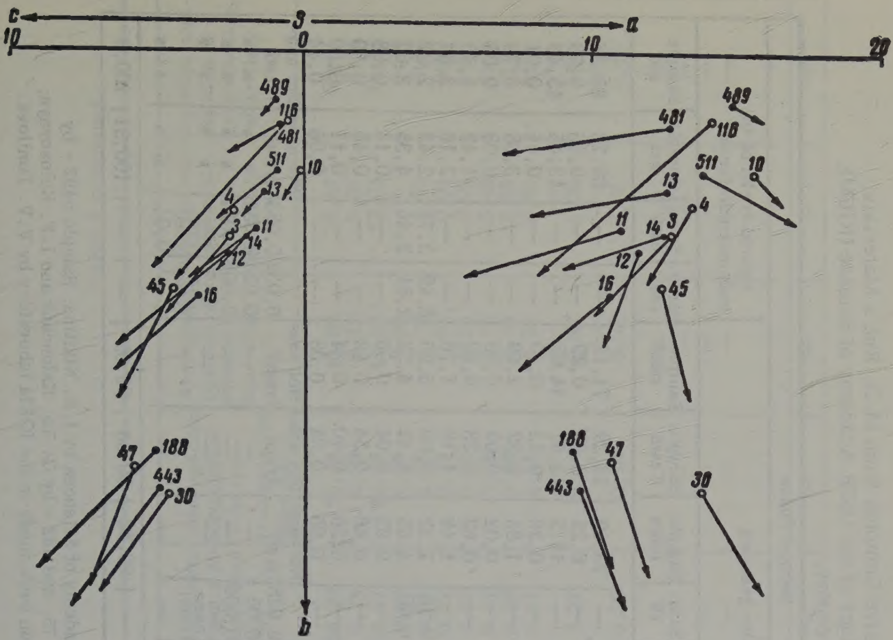


FIGURE 3. Chemical composition of the granitoids of the Myao-Chanskiy intrusive complex.

443, 188 - diorite-monzonite, first phase; 511, 11, 13, 14 - biotite granites, second phase; 489 - alaskite granites, third phase; 481 - tourmaline granites; 12, 16 - granodiorites, facies variety of the second phase; 116 - average composition of alaskites, after Daly; 10 - average composition of alkaline granites, after Daly; 30 - average composition of monzonites, after Daly; 47 - average composition of diorites, after Daly; 45 - average composition of granodiorites, after Daly; 3,4 - average composition of granites, after Daly.

Our studies of the composition of the in-
sive rocks constituting the first phase of ao-Chanskiy complex (up to 500 m deep) owed that oxidation does not increase with oth. This fact is yet another proof contra-ting the view-point of certain geologists o tend to explain the great diversity of the rusives in the investigated area as facies rieties of the large granitoid mass buried depth.[3]

All the aforesaid justifies the supposition t the first-phase intrusives of the Myao-anskiy complex were formed as a result of tonic hybridization (in early structural stage) the limestones, porphyrites, and other rocks h in magnesium and iron by granitic magma.

Analysis of the relationships between the st-phase intrusives and the sandy-shale intry rocks (basin of the Silinka River, the Silinskiy and Kholdominskiy areas) showed that a certain modification in the composition of the intrusive rocks is observed at their contact with the country rocks. This change is less noticeable away from the contact and is no longer traceable 30 to 50 meters away from the contact. These changes attest to the fact that assimilation and hybridization must have taken place in the upper structural stage when the first-phase intrusives of the complex were being intruded. These processes must have been far more intensive during the formation of the second-phase granites. The first-phase intrusives were subjected to silification, sericitization, and tourmalinization. Moreover, in a number of areas these processes were so intensively developed that the rocks were transformed into quartz-sericite and quartz-tourmaline formations. The second-phase intrusives are widely distributed throughout the Chalba River basin, where they form the great Chalba massif (covering an area of about 180 square kilometers) and a number of smaller massifs. They may also be found in the basin of the Silinka River and in other localities.

According to this point of view, gradual oxidation ald occur and normal granites should be found epth.

Table 1

Results of Chemical Analyses of Granitoid Samples of the Myao-Chanskiy Intrusive Complex from M.G. Rub's Materials. The analyses were made in the Chemical Laboratory of the Institute of Ore Geology of the USSR Academy of Science (IGEM). The data (in %) are taken from P.A. Epov's report.

| Elements | First Phase | | | | | | | | Second Phase | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quartzite diorite-monzonites | | | | Diorite-monzonite-porphyries | Granite-monzonites | Quartz diorites | | Coarse-grained biotite granites | | | | | | | | Hybrid rocks of the endomorphic facies | | | |
| | Sample c188 | Sample c443 | Sample c560 | Sample c87 | Sample c301 | Sample c447 | Samp. c448 | Samp. c2 | Sample c511 | Sample c1001 | Sam. c515 | Sam. c490 | Sam. c9 | Sample c4074 | Sample c415 | Sample c3550 | Samp. c491 | Samp. c462 | Sample c12 | Sample c16 |
| $SiO_2$ | 62,81 | 61,14 | — | — | — | — | — | — | 73,72 | — | — | — | — | 73,19 | 73,29 | 71,17 | — | — | 69,73 | 68,26 |
| $TiO_2$ | 0,50 | 0,56 | — | — | — | — | — | — | 0,05 | — | — | — | — | 0,25 | 0,25 | 0,29 | — | — | 0,36 | 0,73 |
| $Al_2O_3$ | 14,83 | 14,75 | — | — | — | — | — | — | 12,15 | — | — | — | — | 14,2 | 13,67 | 14,62 | — | — | 13,45 | 15,43 |
| $Fe_2O_3$ | 0,19 | 1,03 | — | — | — | — | — | — | No out-crop | — | — | — | — | 0,26 | 0,12 | 0,30 | — | — | 0,44 | 0,01 |
| FeO | 5,76 | 5,40 | — | — | — | — | — | — | 2,20 | — | — | — | — | 1,84 | 2,32 | 2,69 | — | — | 3,68 | 3,73 |
| MnO | 0,14 | 0,14 | — | — | — | — | — | — | 0,05 | — | — | — | — | 0,02 | 0,05 | 0,05 | — | — | 0,08 | 0,08 |
| MgO | 3,59 | 3,93 | — | — | — | — | — | — | 0,46 | — | — | — | — | 0,62 | 0,23 | 0,52 | — | — | 1,42 | 1,40 |
| CaO | 6,02 | 6,14 | — | — | — | — | — | — | 1,92 | — | — | — | — | 1,46 | 1,19 | 1,76 | — | — | 2,16 | 3,07 |
| $Na_2O$ | 2,21 | 2,53 | 2,97 | 3,20 | 1,80 | 3,17 | 2,99 | 2,58 | 3,21 | 3,17 | 3,15 | 2,95 | 0,15 | 2,32 | 3,00 | 3,06 | 2,49 | 3,75 | 2,42 | 2,32 |
| $K_2O$ | 3,24 | 2,75 | 3,58 | 3,74 | 2,76 | 3,84 | 2,49 | 2,33 | 5,07 | 5,00 | 5,02 | 4,83 | 6,40 | 4,65 | 4,42 | 4,32 | 2,81 | 2,46 | 4,35 | 3,67 |
| $H_2O^-$ | 0,14 | 0,30 | — | — | — | — | — | — | 0,08 | — | — | — | — | 0,02 | 0,04 | 0,06 | — | — | 0,14 | 0,08 |
| $H_2O^+$ | 0,34 | 1,38 | — | — | — | — | — | — | 0,39 | — | — | — | — | 0,46 | 0,54 | 0,69 | — | — | 0,46 | 0,50 |
| $CO_2$ | 0,28 | 0,12 | — | — | — | — | — | — | 0,28 | — | — | — | — | 0,26 | 0,40 | 0,34 | — | — | 0,11 | 0,50 |
| $P_2O_5$ | Not analyzed | No out-crop | — | — | — | — | — | — | No out-crop | — | — | — | — | 0,05 | 0,04 | 0,08 | — | — | 0,06 | 0,44 |
| $Li_2O$ | 0,038 | 0,02 | 0,03 | 0,03 | 0,025 | 0,06 | 0,022 | 0,032 | 0,04 | 0,046 | 0,030 | 0,03 | 0,028 | Not analyzed | Not analyzed | Not analyzed | 0,032 | 0,083 | Not analyzed | Not analyzed |
| $Rb_2O$ | 0,037 | 0,02 | 0,03 | 0,03 | 0,041 | 0,04 | 0,025 | 0,027 | 0,04 | 0,040 | 0,040 | 0,04 | 0,05 | — | — | — | 0,024 | 0,084 | » » | » » |
| $Cs_2O$ | 0,008 | 0,008 | 0,02 | 0,01 | 0,01 | 0,02 | 0,008 | 0,008 | 0,006 | 0,008 | 0,01 | 0,01 | 0,009 | — | — | — | 0,009 | 0,034 | » » | » » |
| $B_2O_5$ | No out-crop | 0,01 | No out-crop | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | Not analyzed | — | — | — | Not analyzed | Not analyzed | » » | » » |
| F | » | No out-crop | | | — | 0,03 | — | — | 0,03 | — | — | 0,08 | — | — | — | — | — | 0,04 | » » | » » |
| Total | 100,05 | 100,2 | — | — | — | — | — | — | 99,69 | — | — | — | — | 99,42 | 99,56 | 99,95 | — | — | 100,31 | 100,0 |

[1]Samples 188, 443, 511, 481 were analyzed in the Chemical Laboratory of the IGEM of the USSR Academy of Sciences by I.B. Nikitina; Sample c492 - by Ye. Kuznetsova: Samples 148, 148, 2, 301, 447, 560, 87, 1001, 515, 519, 490, 9, 462, 489, 504, 4, 75, and 482 - by G. Ye. Kalenchuk and I.F. Kolosovaya; L. Krutetskaya; Samples 11, 12, 13, 15, are taken from P.A. Epov's report (1957). Analyses for boron were made in the IGEM laboratory by V.V. Danilova.

NOTE: Comma represents decimal point.

Table 1 continued

| Elements | Third phase | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fine-grained biotite granites | | | | Tourmaline-granites | | Average composition of monzonites after Daly | Average composition of diorites, after Daly | Average composition Post cambrian granites after Daly | Average composition of alkaline granites, after Daly | Average composition of alaskites, after Daly | Average composition of granodiorites, after Daly |
| | Sample c489 | Sample c489 | Sample c504 | Sample c475 | Sample c481 | Sample c482 | | | | | | |
| $SiO_2$ | 76,26 | — | — | — | 75,28 | — | 56,12 | 58,90 | 70,18 | 73.80 | 76,47 | 65,01 |
| $TiO_2$ | 0,01 | — | — | — | 0,01 | — | 1,10 | 0,76 | 0,39 | 0,11 | 0,07 | 0,57 |
| $Al_2O_3$ | 12,45 | — | — | — | 12,02 | — | 16,96 | 16,47 | 14,47 | 12,33 | 13,03 | 15,94 |
| $Fe_2O_3$ | 0,07 | — | — | — | 0,63 | — | 2,93 | 2,89 | 1,57 | 2,58 | — | 1,74 |
| FeO | 1,29 | — | — | — | 1,14 | — | 4,01 | 4,04 | 1,78 | 1,28 | 1,04 | 2,65 |
| MnO | 0,02 | — | — | — | 0,02 | — | 0,16 | 0,12 | 0,12 | 0,02 | 0,01 | 0,07 |
| MgO | 0,06 | — | — | — | 0,14 | — | 3,27 | 9,57 | 0,88 | 0,26 | 0,06 | 1,91 |
| CaO | 0,96 | — | — | — | 0,72 | — | 6,50 | 6,14 | 1,99 | 0,46 | 0,45 | 4,42 |
| $Na_2O$ | 3,43 | 3,52 | 2,54 | 3,12 | 2,22 | 2,46 | 3,67 | 3,46 | 3,48 | 4,55 | 3,54 | 3,70 |
| $K_2O$ | 4,98 | 5,28 | 5,94 | 5,46 | 5,65 | 5,60 | 3,76 | 2,11 | 4,11 | 4,20 | 4,81 | 2,75 |
| $H_2O^-$ | 0,20 | — | — | — | 0,18 | — | — | — | — | — | — | — |
| $H_2O^+$ | 0,15 | — | — | — | 1,50 | — | 1,05 | 1,27 | 0,84 | 0,86 | 4,25 | 1,04 |
| $CO_2$ | 0,08 | — | — | — | — | — | — | — | — | — | — | — |
| $P_2O_5$ | 0,03 | — | — | — | 0,35 | — | 0,47 | 0,27 | 0,19 | 0,05 | 0,01 | 0,20 |
| $Li_2O$ | 0,02 | 0,04 | 0,028 | 0,04 | 0,03 | 0,045 | — | — | — | — | — | — |
| $Rb_2O$ | 0,06 | 0,09 | 0,037 | 0,07 | 0,05 | 0,07 | — | — | — | — | — | — |
| $Cs_2O$ | 0,019 | 0,01 | 0,005 | 0,01 | 0,006 | 0,02 | — | — | — | — | — | — |
| $B_2O_5$ | 0,01 | Not analyzed | Not analyzed | Not analyzed | 0,60 | Not analyzed | — | — | — | — | — | — |
| | No outcrop | No outcrop | » » | » » | No outcrop | » » | — | — | — | — | — | — |
| Total | 100,08 | — | — | — | 100,54 | — | — | — | — | — | — | — |

NOTE; Comma represents decimal point.

Table 2

Results of Incomplete Chemical Analyses of Orthoclase Feldspars and of Biotite Granites in the Myao-Chanskiy intrusive complex (in weight %).

| Oxides | Sample $c1001^{k}$ | Sample $c511^{k}$ | Sample $c489^{k}$ | Sample 511 | Sample $c511^{b}$ | Sample $c489^{b}$ | Sample 489 |
|---|---|---|---|---|---|---|---|
| $Na_2O$ | 3,32 | 3,09 | 3,78 | 0,20 | 0,20 | 0,46 | 0,25 |
| $K_2O$ | 11,78 | 12,32 | 11,73 | 8,49 | 8,80 | 8,16 | 8,39 |
| $Li_2O$ | 0,27 | 0,025 | 0,035 | 0,17 | 0,192 | 0,244 | 0,32 |
| $Rb_2O$ | 0,065 | 0,073 | 0,091 | 0,19 | 0,182 | 0,318 | 0,26 |
| $CS_2O$ | 0.01 | 0,008 | 0,01 | 0,06 | 0,051 | 0,10 | 0,06 |
| F | Not analyzed | Not analyzed | Not analyzed | 0,95 | Not analyzed | Not analyzed | 0,75 |

NOTE; Comma represents decimal point.

The second-phase intrusives are represented by coarse grained biotite and biotite-hornblende granites which, in the peripheral parts of the massifs, become granodiorites, quartz-diorites, and diorite-monzonites.

The granitoids of this phase cut and metamorphose the Jurassic deposits of sandy shales and the Upper Cretaceous porphyrites (Pereval'nyy section). At the contact with granites the sandstones and shales are metamorphozed into hornfels and are sometimes slightly greisenized. Tourmaline is found in them in small quantities. Porphyrites along the granite contact are also silicified and sometimes slightly tourmalinized. The thickness of contact aureoles around the massifs produced by second-phase granites ranges from tens to hundreds of meters depending on the character of the contacts. Microscopic examinations have disclosed that the second-phase granites are composed of orthoclase feldspar, quartz, plagioclase (represented by oligoclase), biotite, and hornblende. The auxiliary minerals include zircon, apatite, orthite, monazite, rutile, sphene, garnet, magnetite, cassiterite, and tourmaline. The rock texture is hypidiomorphic-granular, and in some sections, micropegmatitic. Sometimes porphyritic texture may also be observed.

Orthoclase feldspar always predominates over plagioclase in granites. Its contents varies from 30 to 50-55 percent and usually amounts to 40-45 percent. The results of chemical analyses of the orthoclase for $K_2O$, $Na_2O$, $Li_2O$, $Rb_2O$, and $CS_2O$ in the discussed granites (samples 1001, $c511^{k}$) are shown in Table 2.

It may be seen from Table 2 that lithium, rubidium, and cesium are always present in orthoclase feldspars. The $Na_2O$ content in them (from 3.09 to 3.32 percent) is attributable to the large number of perthite inclusions in the albite as shown by petrographic examinations.

The results of spectral analyses of the orthoclase feldspars in the described granites revealed that, apart from rubidium, the characteristic secondary elements of these minerals are: barium (0.0n, rarely 0.n%), rubidium (0.0n, rarely 0.n%), gallium 0.00n to 0.0n%), and copper (from 0.000n to 0.00n%). Moreover, both in theorthoclase feldspars and, particularly, in the plagioclases, boron is invariably present, while strontium (0.0n%) and tin (0.00n to 0.0n%) also frequently occur.

Of the dark-colored minerals, biotite predominates in the discussed granites. The incomplete analysis results of the biotite (sample $c511^{b}$) are given in Table 2. Always present in it are $Li_2O$, $Rb_2O$, and $Cs_2O$, and to a greater extent, in the biotite of third-phase granites.

The results of semi-quantitative spectral analyses of the biotite reveal that rubidium, lithium, barium, zirconium, zinc, gallium are usually present in quantities of 0.0n% with tin and copper amounting to 0.00n%. In certain cases yttrium was found in 0.00n-0.n% niobium in 0.00n% and lead in 0.00n-0.0n% values. Scandium was present in isolated samples.

Of the ferrides, apart from titanium, manganese, and vanadium, small quantities of chromium and nickel are usually present in negligible amounts in the biotite.

The characteristic accessory elements for biotites in the second-phase granites of the complex are, therefore: rubidium, chromium

ium, lithium, zirconium, tin,[4] gallium, and copper. It is interesting that beryllium sually absent, and in those cases when it occur, its contents never exceeded 0.00n%. leading accessory minerals of the second-se granites are zircon, apatite, orthite, siterite, pyrite, tourmaline, magnetite, molybdenite, whereas the principal acces-y elements are barium, strontium, lithium, idium, chromium, zirconium, boron, gal-n, lead, zinc, copper, and molybdenum.

nvestigation of the exomorphic and endo-phic zones of the massifs composed of ond-phase granites disclosed that the gran- themselves are also altered at their con-s with the country rocks. The degree of amorphism diminishes proportionally to distance from the contact. For example, he Chalba massif, in the region of Zabolo-nnyy spring and the headwaters of the Chalba er, one may observe granodiorites and oxene-granites at the very contact with the ntry rocks. As one moves away from the tact they give way to biotite-hornblende nites and then to biotite granites. The oxene granodiorites and biotite-hornblende nites are conspicuous for the uneven dis-ution of dark-colored minerals, unbalanced ntitative and mineralogical composition, other manifestations betraying their hybrid gin. These rocks were probably formed as esult of the assimilation of the country rocks presented by hybrid rocks of the first phase, dstones and schists) and by granitic magma he upper structural stage at the time of nite formation.

The assay results for the second-phase nites, as well as for the hybrid facies of se granites, are given in Table 1 and are own in the diagram of chemical composition gure 3).

From this Table it is obvious that the cond-phase granites — as evidenced by com-ison of analyses results with average types rocks, according to Daly — approximate, content the Post Cambrian granite and differ m it in higher $SiO_2$ and $K_2O$ content and ver MgO, CaO, $Na_2O$, and $Fe_2O$ amounts. $_2O$, $Rb_2O$, $Cs_2O$ and a small amount of on are invariably present in the second-ase granites, just as they are in the first-ase hybrid rocks.

The hybrid facies of the described rocks (samples c491 and 12) correspond to the average types of rocks and occupy an intermediate position between granites and granodiorites (sample 12). The second-phase granites are intruded by dikes of fine-grained biotite granites, aplites, pegmatites and granite-porphyries with north westerly (320°-330°) and north-easterly (30-40°) strike and a steep dip. The dikes range from several centimeters to several tens of meters in thickness. The contact of the dikes with the enclosing granites is sharp. However, the latter display slight silification and greisenization in the immediate vicinity of the contact.

In some sections the second-phase granites are greisenized. Greisenization is manifested in the formation of lithium-bearing muscovite and tourmaline which replace both the feldspars and dark-colored minerals. Sometimes greisenization is so advanced that the granites are transformed into quartzose-micaceous-tourmaline greisens. Zones of intensive silici-fication and tourmalinization associated with lead mineralization occur rather frequently in these granites.

The third phase of the Myao-Chanskiy intrusive complex is represented by fine-grained biotite, alaskite, and tourmaline-bearing granites. In comparison to the second-phase granites, these granites are less widespread. They consist of small massifs not exceeding two square kilometers. The third-phase granites intrude and metamorphoze the Jurassic sandy-shale deposits and the granites of the second phase.

A detailed petrochemical study of the third-phase granites and their comparison with the second-phase facies shows that, along with common features, they possess a number of distinguishing characteristics.

Thus, the biotite granites of the third phase are characterized by:

1. An even greater amount of orthoclase feldspar (50%) and respectively a correspondingly smaller proportion of plagioclase.

2. A more acid plagioclase represented by acid oligoclase.

3. Lack of hornblende and less biotite, whose content does not exceed 2%.

The results of incomplete assays of the biotites of the third-phase granites indicate that they contain more $Li_2O$, $Rb_2O$, and $Cs_2O$ than the biotites of second-phase granites.

4. A greater quantity of cassiterite and tourmaline among its accessory minerals, and the presence of fergusonite. Thus, the leading

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[4]Tin, as previously established by us, is normally sent in the biotites of tin-bearing granites and is found in non-stanniferous granites. Consequently, presence in biotites of this or that type of granite, ng with other indications, bespeaks their stan-erous nature, just as the presence of beryllium the biotites of this or that type of granites, along h other indications, signifies that they contain yllium.

Table 3

Results of X-Ray-chemical Analyses of Zircons and Apatites from the Granitoids of the Myao-Chanskiy Intrusive Complex (in %).

| Elements | First phase | | | | Second phase | | | | Third phase | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Zircon from diorite-monzonites | | Apatite for diorite-monzonites | | Zircon from biotite granites | | Apatite from biotite granites | | Zircon from biotite granites | Apatite from biotite granites |
| | c511 | c230 | c548[a] | c511[a] | c487 | c462 | c487 | c462[a] | c489 | c481[a] |
| Hf | 0,1 | 0,1 | — | — | 0,5 | 0,3 | — | — | 0,5 | — |
| Y | 0,1 | — | 0,1 | 0,2 | 0,5 | 0,3 | 2 | 0.5 | 1 | 2 |
| Ge | — | — | 0,05 | 0,05 | 0,1 | 0,05 | 0,1 | 0,1 | 0,5 | 0,5 |
| La | — | — | — | — | 0,5 | — | — | — | 0,3 | — |
| Pr | — | — | — | — | — | — | — | — | 0,05 | — |
| N | — | — | 0,05 | 0,05 | — | — | 0,1 | 0,1 | 0,3 | 0,3 |
| Gd | — | — | — | — | — | — | — | — | 0,05 | — |
| Dy | — | — | — | — | — | — | — | — | 0,05 | — |
| Er | — | — | — | — | — | — | — | — | 0,05 | — |
| Th | — | — | — | — | — | — | — | 0,2 | 2 | 0,3 |
| U | — | — | — | — | — | — | — | — | 0,3 | — |
| Pb | 0,3 | — | — | — | — | — | — | — | — | — |
| Sn | — | 0,3 | — | — | — | — | — | — | — | — |
| As | — | — | — | — | — | 0,05 | — | — | — | — |

NOTE; Comma represents decimal point.

accessory minerals of third-phase granites are zircon, apatite, cassiterite, pyrite, tourmaline,[5] fergusonite, molybdenum and magnetite.

5. A large proportion of yttrium and elements of the rare-earth group in zircons and apatites of the third phase as compared to second-phase granites (Table 3). Also present in the zircons of the granites are uranium and thorium lacking in the zircons of the second-phase granites.

6. A greater amount of silica and potassium oxide, and smaller proportions of ferric oxide, calcium oxide and magnesium (Table 1, Figure 3).

7. A greater quantity of lithium, rubidium, cesium, and boron (Table 1).

The tourmaline-bearing granites differ from the biotite granites of the third phase by the following characteristics:

1. Two generations of tourmaline are to be observed in them, the tourmaline amounting to 8-10%.[6] The results of incomplete chemical analyses of the tourmalines and tourmaline-granites are recorded below in Table 4.

As this analysis shows, lithium is always present in the tourmalines of tourmaline-bearing greisens and tourmaline rocks, while rubidium and cesium are absent. A somewhat higher percentage of potassium oxide is observable in the tourmalines of the tourmaline-bearing granites as compared to those of the tourmaline rocks.

The results of the spectral analyses of tourmalines extracted from tourmaline-bearing granites showed that the ever-present lithium, zirconium

[5]Particularly interesting is the presence of acicular tourmaline crystals in one of the principal rock-forming minerals — quartz. This tourmaline, which was formed simultaneously with the quartz during the final phases of the magmatic stage, indicates how rich the magma was in boron which began to separate even prior to the end of the actual magmatic stage.

[6]The first-generation tourmaline occurs in the form of well defined prismatic crystals and has a deep reddish-brown or blue color. The first-generation tourmaline is eroded and replaced by quartz and apatite. Sometimes it reveals idiomorphic crystals of zircon surrounded by pleochroic aureoles. Second-generation tourmaline also fills in the small fissures in the rock. In contrast with first-generation tourmaline, it has a light-blue or brownish tint. First generation tourmaline crystallized, probably, by the end of the magmatic process (somewhat earlier than apatite and quartz and simultaneously with them), whereas the crystallization of second-generation tourmaline occurred later in connection with the post-magmatic processes.

Table 4

Results of Chemical Analyses for Individual Tourmaline Components[1] from various rocks of the Myao-Chanskiy Intrusive Complex (in %).

| Elements | Tourmaline-bearing granites, Sample c482 | Quartzitic-micaceous tourmalinic greisens, Sample 488 | Tourmalinized diorite-monzonites, Sample c556 | Tourmaline rocks, Sample c120 |
|---|---|---|---|---|
| $N_2O$ | 2,19 | 2,12 | 2,19 | 2,28 |
| $K_2O$ | 0,27 | 0,24 | 0,18 | 0,19 |
| $Li_2O$ | 0,024 | 0,022 | 0,011 | 0,028 |
| $Rb_2O$ | 0,00 | 0,00 | 0,00 | 0,00 |
| $Cs_2O$ | 0,00 | 0,00 | 0,00 | 0,00 |

[1]The analysis was made at the chemical laboratory of the IGEM of the USSR Academy of Sciences by G.Ye. Kalenchuk.
NOTE; Comma represents decimal point.

ıc, copper, gallium, and vanadium, are char-teristic of them, while yttrium, zinc, stron-ım, and lead also often occur.

2. Biotite is either altogether absent in the ırmaline-bearing granites, or occurs in gligible amounts.

3. Among the accessory minerals there is ss zircon and fergusonite and correspondingly ore apatite.

4. Albitization processes are well developed.

5. Tourmaline-bearing granites, like the otite granites of the third phase, in chemical mposition (Table 1, Figure 3) approximate e average composition of alaskites, as defined Daly, but differ from it by a somewhat lower $O_2$ and $Na_2O$ content and a larger amount of O and $K_2O$. In comparing tourmaline-bearing anites with third-phase biotite granites, we ıd that they closely approximate the latter d are distinguishable from them by a slightly gher percentage of CaO and $Na_2O$ as well as a considerably larger amount of boron.

In a number of sections the biotite and urmaline-bearing third-phase granites are eisenized. Tin ore manifestations are ob-rvable in the exomorphic zones of the tourma-ıe-bearing granites.

As mentioned earlier, dike formations (of erage and basic composition) are widespread the Myao-Chanskiy region even though they e still inadequately studied. A part of ese dikes is directly related to the hybrid ocks of the first phase. Another part, in ır opinion, is, probably associated with the antle of young Tertiary and Quaternary ef-sives (Figure 2). Finally, apparently, there e the dikes and small intrusive bodies which ompleted the formation of the Myao-Chanskiy ıtrusive complex.

The specific characteristics of the three groups of dikes are not yet entirely defined and should become the object of further investigations. At this stage we shall note only that according to available preliminary data, dikes associated with the hybrid rocks of the first phase are characterized by higher potassium content, whereas those that are related to the younger effusive formations are distinguishable by a more basic composition and lack of any mineralization.

In the conclusion of this brief geologic, petrographic, and petrochemical characterization of the Myao-Chanskiy complex intrusive rocks we shall make the following statement. A detailed geologic, petrographic and petrochemical study of the intrusive rocks of all three phases of the Myao-Chanskiy complex makes it possible to postulate that these phases are the derivatives of a single slowly evolving magmatic chamber. The assimilation and hybridization phenomena, which occurred in the initial developmental stages of the magmatic chamber, must have upset the normal course of magmatic differentiation, and caused the appearance of hybrid rocks, on the one hand, and of third-phase granites, on the other, the latter being enriched by alkalies, volatile elements, and ore components.

Comparison of the intrusive rocks belonging to various phases shows that, in spite of a number of substantial differences in their petrographic contents, a set of common features may still be discerned. For example, for the representatives of all phases, even for the first-phase hybrid rocks, a high percentage of potassium and the constant presence of lithium, boron, rubidium, cesium, and tin are characteristic. A gradual decrease in content of iron, magnesium, and calcium, and a gradual increase of silica and alkalis, particularly potassium, are observed from the

first phase to the third. The amount of lithium, cesium, boron, tin, as well as certain other elements, steadily increases from the first phase to the tourmaline-bearing granites of the third phase.

As to the accessory minerals, the proportion of zircon, tourmaline, and cassiterite increases gradually from the first-phase hybrid rocks to the tourmaline-bearing third-phase granites. Apart from zircon, apatite, cassiterite, tourmaline, and molybdenite, fergusonite also may be listed among the leading accessory minerals of the third-phase granites. The amount of yttrium, rare-earth elements, as well as uranium and thorium (Table 3), increases in the zircons and apatites belonging to the more recent phases of the Myao-Chanskiy intrusive complex. This fact allowed us to conclude that the accumulation of yttrium, rare earths, uranium and thorium occurred in the final stages of the magmatic chamber development during the crystallization of the third-phase granites.

All of these factors indicate that the development process in the described magmatic chamber must gradually lead to greater acidification of the magma and its enrichment with volatile constituents and ore components. At the same time the role of calcium, magnesium, and iron gradually diminishes as the significance of silicic acid increased. The observable deviations from this scheme in the Myao-Chanskiy region are attributable to the influences of the enclosing medium.

It is important to note that the intrusives of all three phases of the Myao-Chanskiy complex contains, sometimes more, sometimes less clearly expressed traces of hybridization. However, abyssal assimilation is characteristic for the first phase in the lower structural stage,[7] whereas for the second and third phases, hybridizm is local and traceable directly to the country rocks. Thus, in a number of places in the endomorphic zones of the second-phase granites (the eastern contact of Chalba massif) quartzose diorite-monzonites and granodiorites are observable at the contact with the country rocks. Away from the contact these dioritic facies are gradually replaced by normal granites.

The factual material in our possession attests to the fact that the processes of assimilation and hybridization which developed quite intensively in the initial stage of the magma chamber development, must have somewhat affected the second and third-phase granites during the formation of the first-phase hybrid rocks. Only such an influence explains the presence in third-phase granites (sample 48) — which by their composition resemble alaskites — of a high percentage of calcium oxide and parameter c (Table 1). A study of the young (Upper Cretaceous) granitoids in the Myao-Chanskiy intrusive complex has confirmed the conclusions made earlier by M. G. Rub [9], in the case of the granitoids in the Upper Paleozoic complex (Prikhankayskiy region), to the effect that hybridization processes accompanying the formation of complex multi-phase intrusions occur both in the upper and in the lower structural stages. Moreover, the latter upset the normal development of magmatic differentiation and exerted a certain influence on the specialization of intrusions.

## SEQUENCE OF POSTMAGMATIC FORMATIONS ACCOMPANYING THE GRANITOIDS OF THE MYAO-CHANSKIY INTRUSIVE COMPLEX

In the Myao-Chanskiy region various types of extensive post magmatic formations occur in close areal association with the granitoids of the Myao-Chanskiy intrusive complex (Figure 1). Postmagmatic formations usually coincide with dislocation zones having submeridional trends, or at intersections of dislocation zones having submeridional and latitudinal trends. Studies of the composition and the formative peculiarities of the mineralized zones revealed that their formation progressed in a rather complicated manner and consisted of several stages successively replacing each other in terms of time. These stages are separated by clearly defined periods of intermineralization adjustment.

The following postmagmatic formations were revealed in various mineralized zones of the investigated area (enumeration is made from the earliest to the latest): quartzo-feldspathic metasomatites containing tourmaline or axinite and sphene; quartz-micaceous-tourmaline greisens; tourmaline and quartz tourmaline rocks and the accompanying essentially quartz and quartz-sericite rocks formed as a result of near-vein metasomatic manifestations;[8] combed vein-quartz with a cassiterite matrix, quartz-sulfide, and quartz-carbonate-sulfide ores.

Such a sequence of the described rocks becomes apparent from the structural interrelations of

[7]As previously stated, the intrusives of the first phase were probably formed as a result of deep-seated magma assimilation of sandstones, porphyrites, and other rocks rich in iron and magnesium.

[8]There is no unanimity of opinion on this matter. In particular, V.V. Onikhimovskiy believes that the formation of quartz-sericitic rocks, the essentially quartz rocks ("secondary quartzites"), quartz-tourmalin and tourmaline rocks occurred in four different phases of the hydrothermal stage.

FIGURE 4. Quartzite fragments cemented by younger quartz. (3/4 natural size).

e facies. In speaking of the essentially quartz nd quartz-sericite rocks, one should note at they are confined to the outer portions of e tourmaline and quartz-tourmaline zones. oreover, the quartz-sericite rocks occur etween the essentially quartz and sericitized ountry rocks. The essentially quartz, quartz-ericite, quartz-tourmaline and tourmaline ocks are closely associated with each other. hey were formed in a single process involv-g the action of postmagmatic acid solutions ontaining a high percentage of boron, on ndy shales, effusives and intrusives. Here e principal role is the metasomatic replace-ent of the country rocks and, to a lesser egree, by those of deposition in open cavities.

Investigation of the essentially quartz and uartz-sericite rocks makes it possible to ssume that their formation is related to the anifestation of infiltrative metasomatic oning. Indeed, according to D.S. Korzhin-ky's data [7, 8], several metasomatic zones ust occur along the path of the percolation of cid solutions into the replaceable rocks. loreover, at each metasomatic front between wo zones, the acidity of the percolating solu-on diminishes causing a corresponding de-rease in the solubility of alumina producing artial deposition.

In this manner, replacement must be ac-ompanied by gradual enrichment of the suc-essive metasomatic zones with alumina dis-laced from the zones of total leaching. From this point of view the regular replacement of essentially quartz rocks — the product of total leaching — by quartz-sericite rocks is quite natural. From incomplete analyses of quartz-sericite rocks it appears that lithium ($Li_2O$ - 0.04-0.5%), rubidium ($Rb_2O$ 0.01-0.03%), cesium ($Cs_2O$ - about 0.01%) and boron are always present in them. The results of semi-quantitative spectral analyses show that strontium, zirconium, tin, gallium, lead, zinc, copper, and silver also are characteristic secondary elements of the quartz-sericite rocks.

According to the incomplete chemical analyses of the discussed rocks, and the results of semi-quantitative spectral analyses, the leading accessory elements in the tourmaline and quartz-tourmaline rocks are strontium, lithium, rubidium, cesium, zirconium, boron, with gassium, vanadium, and copper always present. The tourmalines in question differ from the high-temperature tourmalines of the granites in the absence of germanium and yttrium, higher content of vanadium, and the presence of nickel and cobalt.

Cassiterite in smaller quantities is to be found in the greisens and the association of metasomatic rocks referred to above. In the latter case, along with the cassiterite characteristic for the given association, the principal occurrence is superimposed cassiterite deposited in the subsequent quartz-cassiteritic phase of the hydrothermal stage.

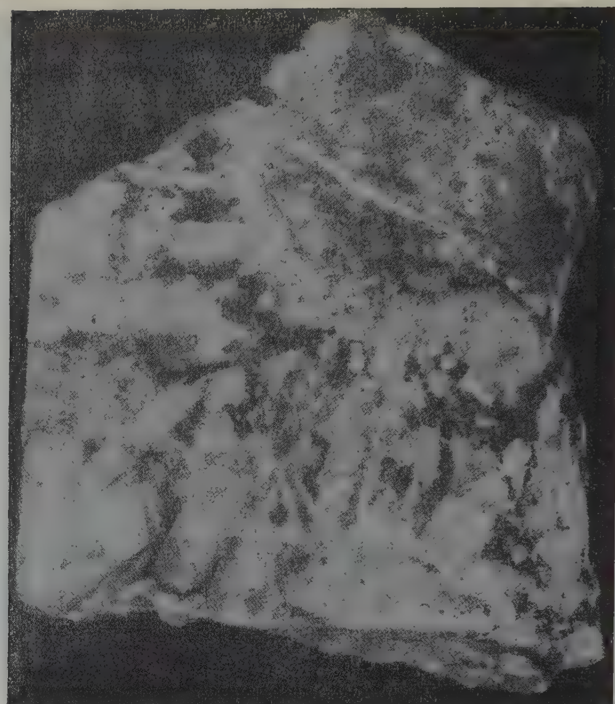

FIGURE 5. Fragments of quartz-tourmaline rocks (right and below intersected and cemented by combed quartz containing cassiterite, sample 615. (3/4 natural size).

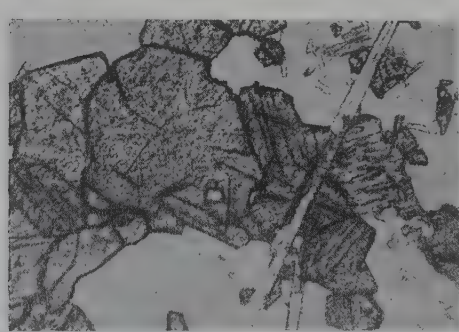

FIGURE 6. Replacement of needle-shaped tourmaline crystals by cassiterite (dark grey). Section 439. Without analyzer. 72 x.

The maximum quantity of cassiterite was deposited together with the combed quartz after the formation of the association of the metasomatic rocks.

This mineralization stage is distinctly separated from the preceeding one (quartz-tourmaline) by an interval of time and intense crushing. Usually the combed quartz containing the cassiterite contains a large quantity of fragments of quartz-sericite, quartz-tourmaline, and tourmaline rocks (Figures 4 and 5). The cassiterite often surrounds and replaces the fragments of quartz-tourmaline and tourmaline rocks (Figure 5) and the individual tourmaline crystals (Figure 6). Numerou semi-quantitative spectral analyses of the cassiterites revealed the invariable presence in them of niobium in quantities ranging from 00.n to 0.0n%. Frequently, lead may also be noted, and sometimes antimony.

The final stage of minero-genesis is the ...rtz-sulfide-carbonaceous stage, during ...ich an important role is played by the car-...nates represented mainly by calcite and ...erite. Ordinarily, these minerals fill in ... hollows between the previously deposited ...rtz crystals, or they form stringers pene-...ting the previously formed hydrothermal ...ks. The low-temperature sulfides — ...ite, galenite, sphalerite, and chalcopyrite ...are developed in the veinlets along with the ...cite and quartz.

In summing up all of the above discussion ...this section, it is possible to draw the ...lowing basic conclusions.

1. The formation of mineralized zones is ...ong and complicated process. It consists ...several phases and stages successively re-...cing each other. Thus, the greisen stage ...replaced by a lower-temperature hydrother-...l stage comprising several phases; quartz-...rmaline, quartz-cassiterite, quartz-sulfide, ...d quartz-sulfide-carbonate. These phases ...e usually separated by well-defined periods ...inter-mineralization, and follow each other ...er a certain interval.

2. In the formative process of the mineral-...d zones an exceptionally important role is ...yed by metasomatic processes, which is ...ributable to favorable structural circum-...nces and the high mobility of the metallif-...ous solutions which, as a rule, are rich in ...atile constituents, particularly boron.

3. A definite regularity exists in the mani-...tation of the described types of mineraliza-...n. For example, the early mineralization ...ges are most extensively developed in ...d near the granodiorite massifs whereas the ...e stages are at some distance from the in-...sions.

### Relationship Between Mineralization and the Granitoids of the Myao-Chanskiy Intrusive Complex

The intrusives belonging to all three phases ...the Myao-Chanskiy intrusive complex and ...e associated vein rocks are intersected and ...placed by a variety of types of postmagmatic ...mations extensively developed in the in-...stigated area. They are very heavily silici-...d, sericitized, and tourmalinized.

At the present time several facts have come ...hand which makes it evident that the well ...veloped stanniferous and polymetallic min-...alization in the Myao-Chanskiy region is ...lated to the development of a composite ...neous complex.

Among these facts one should point out the ...lowing.

1. The areal association of the mineralization with the intrusives of all three phases of the Myao-Chanskiy complex (Figure 1).

2. The horizontal zoning in the distribution of various types of post-magmatic formations. For example, the earlier and high-temperature minerogenetic stages are most widely developed in the intrusives and in their vicinity, while more recent and low-temperature types of mineralization occur away from them.

3. Comparable depths of formation of the intrusives and the ore bodies. According to our estimates, the formation of the intrusives in the Myao-Chanskiy region must have occurred at a depth of 1.5-2 kilometers. The various postmagmatic rocks were also formed at approximately the same depth.

4. Development of the same types of minerals in the later stages of cooling in the intrusives and in the various postmagmatic formations. Thus, among the third-phase granites of the Myao-Chanskiy igneous complex one finds tourmaline-bearing granites, the tourmaline being formed at the end of the actual magmatic stage. In addition, the second- and third-stage granites show signs of greisenization associated with autopneumatolysis. The greisenized granites and greisens, as well as quartz and muscovite, always contain tourmaline. Tourmalinization occurs in the exocontact aureoles of the intrusives belonging to all three phases. At the same time, tourmaline is the leading mineral of various postmagmatic formations so abundant in the Myao-Chanskiy region.

It is evident from the above that the magma which was responsible for the formation of the Myao-Chanskiy granitoid complex and the accompanying postmagmatic rocks was enriched with boron. The separation of boron began in the early stages of development of the magmatic chamber during the crystallization of granites, and the accumulation occurred later in connection with the action of postmagmatic processes.

5. The presence of cassiterite among the accessory minerals of the granitoids belonging to all three phases of the Myao-Chanskiy complex and the associated vein rocks.

6. Geochemical affinity of the granitoids of all three phases of the complex and the accompanying postmagmatic formations. The available factual material permits the singling out of a group of transient elements whose deposition began in the early stages of the development of the magmatic chamber during the crystallization of the granitoids of the Myao-Chanskiy intrusive complex. Accumulation took place later in connection with postmagmatic activity. These elements include: lithium, rubidium, cesium, copper, strontium, boron, tin, tungsten, gallium, lead, and zinc


FIGURE 7. Geochemical Diagram of the Granitoids in the Myao-Chanskiy intrusive complex and the associated postmagmatic formations.

1 - trace - elements characteristic of the first-phase hybrid rocks; 2 - trace - elements characteristic of the second-phase granitites; 3 - trace - elements characteristic of the third-phase granites; 4 - trace - elements characteristic of all postmagmatic formations; 5 - trace - elements characteristic only of high-temperature post-magmatic formations; 6 - trace - elements sometimes observable in granitoids.

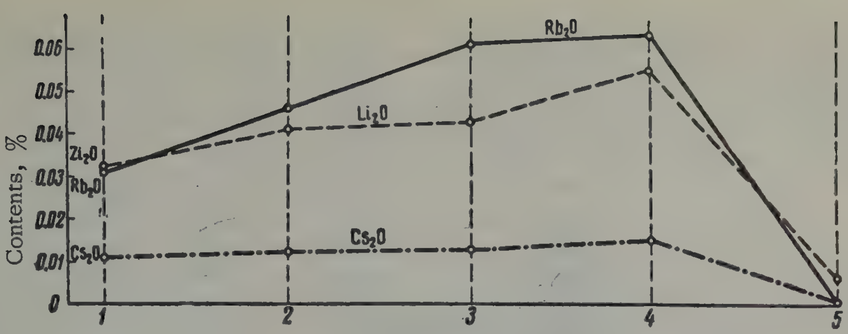


FIGURE 8. Variation of cesium, rubidium, and lithium content in the granitoids of the Myao-Chanskiy igneous complex.

1 - Phase I: diorite-monzonites; 2 - Phase II: biotite and biotite hornblende granites; 3 - Phase III: biotite, alaskite, and tourmaline-bearing granites; 4 - high-temperature postmagmatic formations: greisens, sericite and quartz-sericite rocks; 5 - lower-temperature postmagmatic formations: quartz-tourmaline and tourmaline rocks.

igure 7). Some of these elements, particu-rly boron, rubidium, and cesium, are present the representatives of all three phases of the yao-Chanskiy complex in quantities above arke values. Other metals — tin and lead — pear in amounts exceeding Clarke values ly in the tourmaline-bearing granites of the rd phase. It is interesting to note that the hium, rubidium, and cesium content in-eases gradually from first-phase to third-ase rocks and is maximum in the high-mperature postmagmatic formations: greisens d quartz-sericite rocks. In the lower tem-rature postmagmatic formations the propor-on of the mentioned elements again decreases igure 8). The maximum content of boron d tin also increases from the first-phase cks to the tourmaline-bearing granites of e third phase. For boron, the peak is reached the tourmaline rocks, for tin - at a more cent stage coinciding with the formation of e combed quartz.

All of the factual material at our disposal — ich is only partially discussed in this ticle — evidences that tin mineralization, despread in the investigated area, is asso-ated with the chamber responsible for the rmation of the Myao-Chanskiy intrusive com-ex granitoids. The separation of metalliferous lutions from the magma occurred repeatedly, t the maximum amount was segregated after e formation of the tourmaline-bearing granites the third phase and represents a derivative the residual magmatic melt saturated with latile constituents and ore elements.

A close genetic relationship can be estab-shed in the Myao-Chanskiy region between the latively high-temperature ore manifestations the greisen and cassiterite-quartz types d the relatively lower temperature cassiterite-quartz-sulfide and sulfide ore manifestations. Therefore, if the genetic association of the greisens and tin mineralization with the granitoids of the Myao-Chanskiy complex appears to be beyond doubt, then the cassiterite-quartz-sulfide and sulfide mineralizations must also be related to the same chamber as parts of a single process.

## SUMMARY

Studies of the granitoids in the Myao-Chanskiy igneous complex showed that they are specialized, and confirmed our conclusions formulated earlier for the case of the Prikhankayskiy region [9] concerning the existence of specialized intrusions. Comparison of the specialized intrusions of different age in different structure-facies zones revealed that, along with common features, they also possess a number of specific petrochemical characteristics. Thus, for example, the Upper Paleozoic specialized intrusions of the Grodekovo complex (Prikhankayskiy region) confined within the limits of the Khanayskiy tectonic massif and the Upper Cretaceous granitoids of the Myao-Chanskiy intrusive complex (Komsomol'skiy district of Khabarovsk Kray) located in the zone of Cretaceous folding,[9] in addition to these common features, possess a number of specific petrochemical characteristics. Both the former and the latter belong to the multi-phase type, and in both cases there was a gradual increase in oxidation and potassium content in the rocks from the earliest phases to the more recent ones. Quite characteristic of both is the extensive

[9]Towards the Cenozoic the entire western part of lower Priamur'ye, including the Komsomol'sk district, became stable and approximated platform conditions.


FIGURE 9. Geochemical diagram of granitoids in Grodekovo intrusive complex and the accompanying postmagmatic formations. (The designations are the same as in FIGURE 7).

velopment of hybridization processes occrring both in the upper and lower structural ges. The leading accessory minerals of Upper Paleozoic granitoids in the Grodekovo rusive complex are zircon, apatite, rutile, orite, cassiterite, and magnetite. In the per Cretaceous stanniferous granitoids of Myao-Chanskiy intrusive complex the preent accessory minerals are zircon, apatite, hite, cassiterite, tourmaline, magnetite, lybdenum, and fergusonite. Characteristic the former are such accessory elements as rium, beryllium, lithium, zirconium, anium, fluorine, boron, tin, gallium, and d (Figure 9); and for the Myao-Chanskiy neous complex these are: cesium, rubidium, rium, lithium, zirconium, gallium, copper, d lead. Typical of the third-phase granites this complex are also molybdenum, uranium, rare earths, and niobium.

Thus, the stanniferous granitoids of the ao-Chanskiy igneous complex — along with umber of such common petrochemical tures as abundance of potassium, tin, on, lithium, and rubidium — posses a of peculiarities which distinguish them m the Upper Paleozoic granitoids of the odekovo intrusive complex. These peculities include:

1. A distinctly subordinate role for fluorine l a far greater importance for boron. In granitoids of the Myao-Chanskiy intrusive nplex and in the associated postmagmatic mations, fluorine has a very limited disbution, whereas in the granitoids of the odekovo igneous complex it is a dominant ment.

2. The role of beryllium is distinctly subinate. In the granitoids of the Myaoanskiy intrusive complex beryllium rarely urs and always in quantities far below rke values.

3. Cesium is always present. Cesium in all quantities occurs in the granitoids of three phases of the Myao-Chanskiy insive complex, but attains its maximum he high-temperature postmagmatic formas (Figure 7), and is absent in the lowperature facies.

4. The presence among the accessory herals of the third-phase granites of the ao-Chanskiy intrusive complex of fergusonite ich does not occur in the granitoids of the odekovo intrusive complex, and other inations.

All the materials discussed herein also tify to the major role of petrochemical teria in establishing the character of the ationship between mineralization and magtism. Moreover, comparison of specialized intrusions of different age in different structure-facies zones show that, along with a number of common features, they possess certain specific petrochemical characteristics.

The above conclusions must be verified in other regions.

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Institute of Mining Geology, Petrography, Mineralogy, and Geochemistry, U.S.S.R. Academy of Sciences,
Moscow

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# MAGNETIC-FRACTIONAL-MINERALOGICAL STUDIES OF ROCKS[1]

by
F. N. Yefimov

I presented a report on the first results tained in making a magnetic-frictional-ineralogical analysis (MFMA) of various cks and ores, mainly from the Ukrainian ield, and partly from the Kusrk Magnetic iomaly, at the Second All-Union Petrographic onference held in May 1958 in Tashkent.

Investigations were carried out during the cond half of 1958 and in 1959 to improve the ethod and verify the effectiveness of using ese analyses to study the composition and the agnetizability of crystalline rocks exposed drilling in Western Bashkiria and Eastern rtaria. At the same time the improved FMA method was used to investigate certain pes of magmatic and metamorphic rocks om the Ukrainian Shield, the Chernigov rings, the Urals, and ores from the Caucasus d Eastern Siberia; such as gabbros, olivine bbro, gabbro-amphibolites, gabbro-anorthotes, gabbro-diabases, basalts, diabases, roxenites, diorites, andesites, quartz diotes, granodiorites, granosyenites, syenites, agiogranites, hybrid granites — amphiboles, nphibole-pyroxenes, and pyroxenes, charnokes, amphibolites, skarn-type rocks, granoorite-gneisses, gneisses (biotitic, amphibole-otite, amphibole-biotite, garnet-biotite, rnet-biotite-sillimanite, cordierite, and hers), magnetitic and hematite-magnetite artzites, magnetitic hornfels and schists, agnetitic websterites and ores, pyrrhotite d hematite ores.

This diversified assemblage of rocks and es was required in order to determine the neral nature of the relationships between e MFMA parameters and the composition geologic formations of different origin and etamorphism.

Altogether about 500 analyses were made. bviously, the number of samples investigated us is not sufficient to define concretely e revealed mineralogical and physical regularities with respect to each of the enumerated varieties of rocks. However, the data at our disposal, and the considerable number and diversity of rock samples analyzed by us during the first development of MFMA, provide sufficient grounds, even now, to recommend the magnetic-fractional-mineralogical analysis for widespread use by geologic and geophysical organizations. As MFMA is gradually put to use in solving various geologic survey problems, the areas of its effective application will become more precisely evident. At the same time new factual material will be collected characterizing the details and peculiarities of the mineralogical and physical relationships between rocks of the same type, even if they are from widely separated areas and of different ages.

The newly developed analytical method was designated as a magnetic-fractional-mineralogical analysis because it is based on the utilization of the magnetic properties mostly of ferro-magnetic minerals occuring in nature, on the peculiarities of the distribution of these minerals in the separation process of the rock-powder batch and its segregation into magnetic and "non-magnetic" fractions.

The MFMA diagram shown in Figure 1 gives a good idea of the nature and sequence of operations involved in the analysis. The principal operations are:

1. Determination of the magnetic susceptibility ($\varkappa$) of the original rock powder with grains measuring less than 0.25 mm.

2. Separation of the initial batch (1-2 g) of rock powder, with grains of less than 0.15 mm, in the field of a permanent electromagnet by the wet process method under rigidly fixed and identical conditions for all analyzed rocks ($H = \sim 900$ e).

3. Weighing of the magnetic fraction with a 0.1 mg accuracy and determination of parameter Fp equivalent to the weight percentage of ferro-magnetic minerals in the powder.

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[1]Magnitno Fraktsionno-Mineralogicheskoye ichenie Gornykh Porod. pp. 24 - 36.

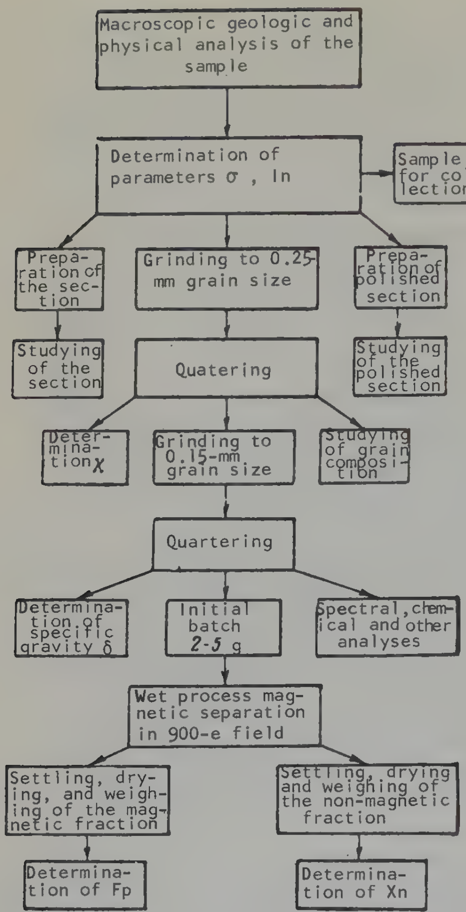


FIGURE 1. Diagram of the successive steps in magnetic-fractional-mineralogical analysis.

4. Determination of the magnetic susceptibility of the "non-magnetic" fraction ($\varkappa_n$) characterizing the contents and quality of the ferromagnetic minerals not attracted to the poles of the electromagnet under given separation conditions, and determination of the magnetizability of the paramagnetic minerals of the rock.

It is known that the magnetization intensity of ferromagnetic material (J) is proportional to its magnetic susceptibility ($\varkappa$) and the intensity of the magnetizing field (H)

$$J = \varkappa H.$$

Considering the fact that separation proceeds at a single and constant value of H, the magnetization intensity is directly proportional to the degree of susceptibility.

In the general case, a ferromagnetic material possesses not only inductive, but natural residual magnetization Jn, as well. Then

$$J = \varkappa H + Jn.$$

i.e., the force attracting the particles to the poles of a permanent electromagnet depends not only on the susceptibility of the ferromagnetic material, but also on the magnitude of its natural residual magnetization. It is obvious that those particles which are more powerfully attracted to the poles apart from equal susceptibility values, also have some residual magnetization.

Under the selected separation conditions the overwhelming proportion of the relatively large ferromagnetic separates get into the magnetic fraction. The small ferromagnetic separates which are intimately intergrown with their silicates (pyroxenes, amphiboles, biotite, olivine, garnet), or ores (ilmenite, hematite, pyrite) minerals migrate into the "non-magnetic fraction. Fine ferromagnetic particles settle into the "non-magnetic" fraction, first of all, because of their relatively weak magnetization - the coarser particles always have a higher $\varkappa$ - value than the fine ones. In the second place, this happens because their magnetic gravitation to the poles of the electromagnet turns out to be inferior to the gravity of the carrying silicat or ore minerals.

Depending on the composition of the investigated rocks, ferromagnetic materials with a definite composition, morphology, and in given quantities, will get into the "non-magnetic" and magnetic fractions. In accordance therewith, definite values of Fp (weight percentage of ferromagnetic material) and $\varkappa$ n, which constitute the basic initial parameters of magnetic-fractional-mineralogical analysis, will be obtained for each variety of rock.

Among the initial MFMA parameters one should also include parameter $\varkappa$. This parameter is measured under the specific conditions of the proposed analysis and characterizes the quantity, composition, and quality of the ferromagnetic materials contained in the initial batch of the investigated rock.

The ratios of the above three initial parameters make it possible to determine three very important additional parameters, namely:

$$\text{parameter} \quad M = \frac{\varkappa}{\Phi c},$$

$$\text{parameter} \quad H = \frac{\varkappa_н}{\varkappa},$$

$$\text{parameter} \quad O = MH = \frac{\varkappa_н}{\Phi c}.$$

In addition to the enumerated parameters the MFMA complex also has three known very important parameters — natural residual

magnetization (Jn), parameter $Q = \frac{Jn}{Ji}$, and the volume weight of the rocks ($\sigma$).

If required, the number of physical parameters to be used may be increased by introducing such quantities, for instance, as specific gravity, total porosity, the Curie point. However, a larger number of parameters cannot substantially affect the effectiveness of MFMA, which is basically determined by the six specific parameters and density.

A study of sections and polished sections is required to interpret the physical and geological nature of MFMA parameters. Chemical, X-ray diffraction, spectral and other types of analyses also may be made on a moderate scale for the same purpose.

Of particular importance in a correct interpretation of MFMA data is the mineralogical study of the ferromagnetic minerals, not only of ferruginous formations, but for any types of rocks.

In studying polished sections of rocks using different values for MFMA parameters, it has been possible to establish the fact that ferromagnetic minerals in rocks are represented predominantly by magnetite and its varieties: titanomagnetite, magnesioferrite, and sometimes maghemite, muschketowite, and certain others, as well as by pyrrhotite. Magnetite and its variants are exceedingly widespread in nature and may be encountered in some concentration or other in almost all geologic formations of acid, alkali, basic, or ultra-basic composition of magmatic or metamorphic origin. Pyrrhotitic mineralization is far less abundant in nature and is usually found in rocks affected by hydrothermal alteration.

The described ferromagnetic minerals occur in rocks in various forms of separates diversely associated with other rock-forming minerals, and with varied composition. One may, for instance, observe primary magnetites belonging to several generations, and magnetites of secondary origin separated as a result of geochemical transformations of silicates or ore minerals caused by metamorphic processes. Allotriomorphic forms are characteristic of the primary precipitations of magnetite. This is because this mineral was precipitated after many silicate rock-forming minerals and filled their intergranular spaces. The secondary precipitates of magnetite are concentrated within the minerals which are responsible for their formation. These are considerably finer grained than the primary magnetites.

We are not yet in a position to provide a more or less conclusive classification of the forms of the primary and secondary magnetitic separates since the data available on this matter are still insufficient. In particular, it is still difficult to explain the nature of the fine deposits of magnetite which can be found more or less evenly distributed in certain types of basic rocks. Are they a more recent generation of primary precipitates, or do they represent a special form of secondary magnetitic deposition? There still is no differentiated characteristic of the secondary magnetitic separates formed as a result of the opacitization, amphibolization, biotitization, and chloritization of silicate minerals.

However, the data at our disposal convince us that all these questions will be answered in the process of further detailed rock investigations using MFMA. Moreover, these data make it possible, even today, to define the over-all character of the relationship between the MFMA parameter values and the forms of the magnetitic separates in rocks having different composition, metamorphism, and genesis.

It has also been established that pure separates of magnetite occur rather unfrequently. Often they contain inclusions of other ore minerals. More frequent are the inclusions of ilmenite and rutile. In titanomagnetite sometimes contains hematite inclusions. When isomorphous admixtures of magnesium, chromium and other metal oxides are present in magnetite, the mineral is referred to as magnesiaferrite, chromomagnetite, etc. Here, as in the case of titanomagnetite, the ferromagnetic properties are retained by the magnetite, while the isomorphous admixtures of other metal oxides play a passive role, i. e. having the significance of paramagnetic inclusions. In speaking of passivity, we have in mind the very low susceptibility of paramagnetic inclusions. But the role of the latter can not be defined as passive when one considers the natural residual magnetization of some types of basic rocks. Under definite conditions the xenolith plates may play the role of energy barriers in the process of natural demagnetization of rocks.

It is a well-known fact that magnetite and its varieties oxidize (martitize) in supergene zones, i. e. turn into hematite, and subsequently also into hydrous ferric oxides (limonite). It is also known that in a reducing atmosphere hematite may turn into magnetite (muschketowite). In a number of cases, for example, in special investigations of iron-ore formations the processes of magnetite martitization and hematite muschketiwization may present a matter of independent practical and scientific interest and be studied with MFMA parameters. When, however, rocks become the object of investigation, the processes of martitization not only fail to help, but actually hamper, and at times render impossible, the exposure of natural connections between general mineralization and ferromagnetic mineralization. To avoid gross errors in interpreting the nature of MFMA parameters, samples containing deep-seated martitization of magnetite should be discarded before examination.

Special attention should be given to maghemite. Until recently most investigators considered this mineral as a ferromagnetic variety of hematite (5, 8). MFMA studies of several maghemite-bearing samples of magnetite from the Kezhma deposits, a maghemite specimen and a few hematitic and magnetitic ore samples from deposits located elsewhere in the Soviet Union, lead us to conclude that maghemite is actually a form of oxidized magnetite. The spinel-type cubic structure of magnetite is preserved in maghemite and the difference between the two minerals is that a part of divalent iron ions is replaced in maghemite by trivalent ions. The quantitative ratio between the di- and trivalent iron ions accounts for the fact that maghemite displays lower susceptibility and higher residual magnetization than magnetite. Maghemite is, probably, widely disseminated in nature and is present in small quantities not only in some types of hematite and magnetite ores, but also in rocks with different compositions. This explains the anomalously high residual magnetization values of these formations. This question will be answered conclusively in the process of subsequent investigations of various types of rocks and ores in which MFMA is used. Because of these maghemite inclusions and because their optical properties closely resemble those of hematite, the magnetic properties of maghemite may be attributed to hematite erroneously.

Mineragraphic studies or rocks with varying MFMA parameters made it possible to further clarify the confusing problem of the nature and character of the magnetization of rock-forming minerals. It is well known that many textbooks, monographs, and handbooks include lists of minerals giving the values of their magnetic susceptibility, natural residual magnetization, and other magnetic parameters. Such ores as ilmenite, hematite, even limonite, are described as ferromagnetic minerals (10). Almost all ferrous silicate minerals are shown as possessing a wide range of $\varkappa$ values varying from a few $10^{-6}$ to $10^{-4}$ - $10^{-3}$ CGS$\mu$. Actually, however, the mentioned and all other iron-bearing silicate minerals (olivine, pyroxene, amphiboles, garnets, biotite, etc.) are paramagnetic. The ferromagnetic properties frequently discovered during the physical measurements of such minerals are attributable to the minute inclusions of magnetite and other ferromagnetic materials, whose presence, as a rule, disregarded.

Petrographic analyses which are included in the MFMA complex permit evaluations to be made of the general mineralogical composition of the investigated rocks, and to better the degree and character of the metamorphism, as well as the peculiarities of distribution and morphology of the ore formations.

In practice geophysical organizations engaged in studying the physical properties of rocks are as a rule, known to be rather unconcerned about such matters as determination of elementary composition and the nomenclature of the investigated geologic formations. As a result cases frequently occur when physical properties are inconsistent with the names of the rocks. This situation has developed because of a lack of proper theoretical and methodical investigations of the natural geological and physical relationships.

The magnetic-fractional-mineralogical analysis promises to put this matter in better order, because this analysis provides for close coordination of magnetic and mineralogical studies. As the MFMA was being improved in the research process, the physical and petrographic methods of rock investigation gradually became more and more interdependent. If at the early development stages of the analysis physical and geologic characteristics were merely compared, during the later stages they were used as mutual checks, and to determine reasons for the noted inconsistencies between the magnetic and mineralogical characteristics. In most cases repeated measurements revealed erroneous determinations and the inconsistencies could thus be eliminated. Whenever the repeated observations failed to remove these inconsistencies, they served as the basis for a search for new geologic and physical relationships still unreflected in the determined regularities.

It is well known that a single-value determination of a rock's name with a microscope is not an easy task, and is often difficult, particularly if the rock is a hybrid or metasomatic formation. It is recommended that MFMA parameters be used for a more precise determination of rock compositions.

Let us now revert to the MFMA results of the rocks investigated by us. The symbols in Figure 2 designate the areas, or zones, of distribution of the rock samples depending on the magnitude of their magnetic susceptibility ($\varkappa$) and parameter Fp. In order to avoid obscuring the drawing, only three lines of identical M values corresponding to 100, 1000, and 10,000 were drawn. As may be seen, each zone has a perfectly definite position within the area bounded by lines M = 100 and 10,000, and a very definite, though generalized, designation based on the elementary composition of the rock sample, is assembled therein.

In the middle section of the area there are three zones: hybrid granites, gabbroids, and effusive analogs of gabbroids. The granitoids have the highest values of parameter M = 1000 - 1600, the lowest (M = 200-500) are characteristic of basalts. The intermediate values of this parameter correspond to gabbroids.

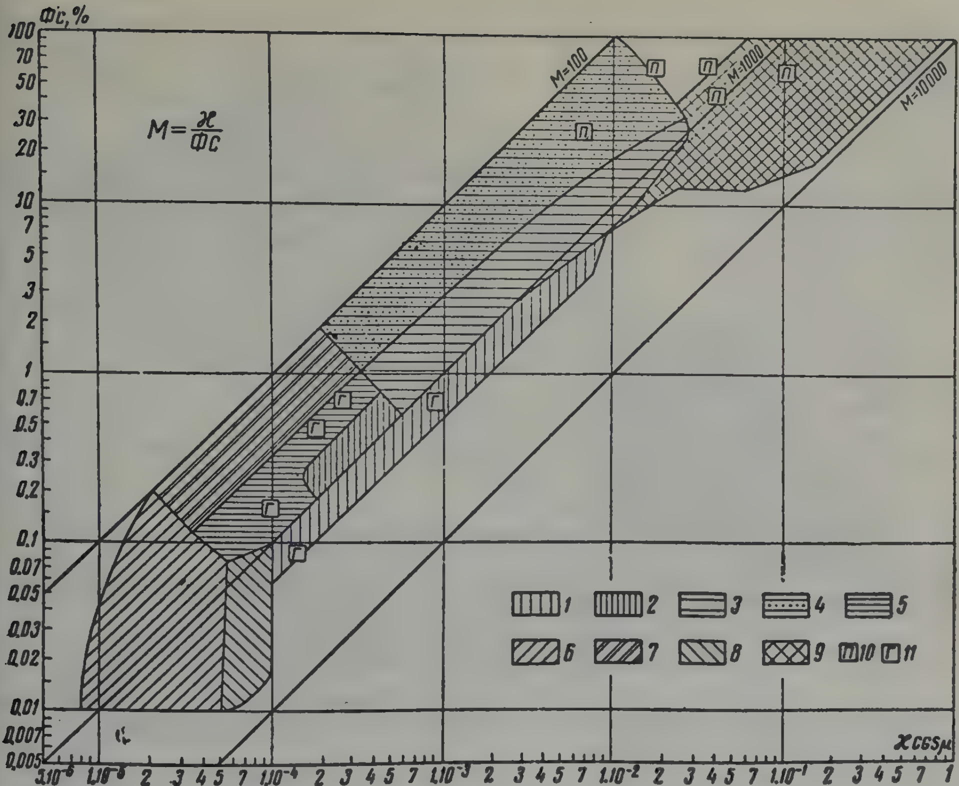


FIGURE 2. Magnetic susceptibility of crystalline rocks in Volga-Uralian region, the Ukrainian Shield, and other areas as a function of the percentage of ferromagnetic minerals in them.

1 - zone of hybrid granitoids; 2 - zone of granodiorite-gneisses; 3 - zone of gabbroids; 4 - zone of basalts; 5 - zone of altered gabbroids; 6 - zone of biotite, biotite-amphibole-chlorite, garnetiferous biotite gneisses; 7 - zone of garnet gneisses and metasomatic skarn-type rocks; 8 - zone of amphibolites and amphibole-chlorite schists; 9 - zone of magnetite quartzites, hornfels, schists, and ores; 10 - pyrrhotite ores; 11 - hematite ores.

Is this distribution of samples of acid and asic magmatic rocks accidental? No, it onforms strictly to established law and is ue to the fact that magnetite, free of inclusions, appears as the chief ferromagnetic naterial in granodiorites, granosyenites, lagioclases and pyroxene granites which nake up the zone of hybrid granitoids. When itanomagnetite occurs in the rocks along with nagnetite the value of parameter M diminishes. Ferromagnetic minerals form large allotrionorphic bodies occupying the intergranular paces in the samples of hybrid granitoids. n the gabbro, olivine gabbro, and gabbroliabases of the intermediate zone, the ferronagnetic component is titano-magnetite, i. e. nagnetite in which ilmenite inclusions comprise rom 10 to 50% and more of the total volume of he large primary anhedral ferro-magnetic egregates. In addition, secondary magnetite is present in all gabbroids — as well as ultrabasic rocks (pyroxenites and peridotites) — in large quantities as fine punctate inclusions associated with the grains of pyroxenes and amphiboles. In basalts and andesites, as well as in basaltic diabases, the ferromagnetic mineral is titanomagnetite in which the predominant component is not magnetite, but ilmenite. At the same time, ferromagnetic deposits in the basic effusives are very small in size (on the order of a few units to tens of microns). Because of this their parameter M values are the lowest.

In this manner it is possible to make a genetic classification of acid and basic magmatic rocks on the basis of parameters ϰ, Fp, and M. Rocks of average composition — diorites — occupy an intermediate position between the granitoids and the gabbroids.

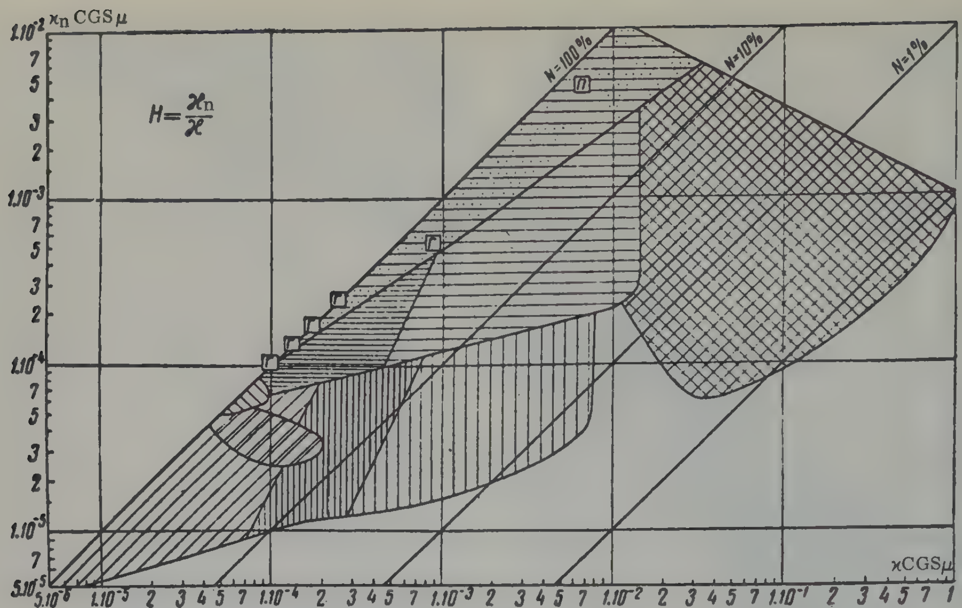


FIGURE 3. The $\varkappa$ to $\varkappa_n$ ratio for crystalline rocks from the same regions. (Designations in this and the following diagrams are the same as in Figure 2).

In the upper right section of the diagram there is a zone of ferruginous formations. The highest parameter M values, up to 5000-6000, are manifested by ores and quartzites made up of primary magnetite deposits forming massive aggregates or ore bands. The lowest M values characterize pyrrohotite ores. The intermediate values of this parameter pertain to amphibole magnetite hornfels and schists which, in addition to primary magnetite, also contain secondary magnetite associated with silicate intercalations or minerals. Certain types of these rocks also contain titanomagnetite deposits along with those of magnetite. The samples of hematite ores represent the zones of altered gabbroids and granitoids and have lower values for parameter M = 400-1500.

It is known that pyrrhotite ores may possess ferromagnetic and paramagnetic properties (1). The five samples of pyrrhotite ores from different deposits in Eastern Siberia and the Kola Peninsula examined by us turned out to be ferromagnetic, but having a wide range of parameter M values equal to 300-1000. Mineragraphic investigation of the pyrrhotite ores showed that the high values of this parameter characterize magnetic pyrites containing inclusions of magnetite. Samples without magnetite inclusions had low values for parameter M = ~ 300. Consequently, it is also possible to construct a genetic classification for ferruginous formations with the aid of parameters $\varkappa$, Fp, and M.

Several zones are located in the lower left section of the diagram. These are the zones of altered gabbroids, altered granitoids, gneisses, skarn-type rocks, and amphibolites.

The zone of altered gabbroids includes gabbro-amphibolites and amphibolites; the zone of altered granitoids consists of granodiorite-gneisses; the zone of gneisses incorporates biotite, garnetiferous biotite, sillimanite-biotite, and cordierite facies; the zone of amphibolites supposedly consists of para-amphibolites, amphibole-chlorite schists and diabases. Characteristic of all these rocks is a negligible quantity (in gabbro-amphibolites), or total absence (in gneisses and amphibolites) of primary magnetite. In view of this fact, weak magnetization of these rocks is, to a considerable extent, or entirely, due to the thin intercalations of secondary magnetite. This is the reason that small values of parameter M (less than 1000) were registered for the bulk of these samples. Only in weakly magnetic samples containing very low ferromagnetic mineralization parameter M was found to be sharply increased to 5000-7000 and higher.

The zone of skarn-type formations contains concentrated metamorphic rocks enriched by garnet. Typical of these rocks is pyrrhotitic mineralization and a corresponding low value of parameter M = 200-300.

Figure 3 shows the distribution character of the zones from which the examined samples were taken and its relationship to the ratio of parameters $\varkappa$, $\varkappa$ n, and H. Since the values of one and the same parameter (susceptibility) are plotted in this and the preceeding diagrams

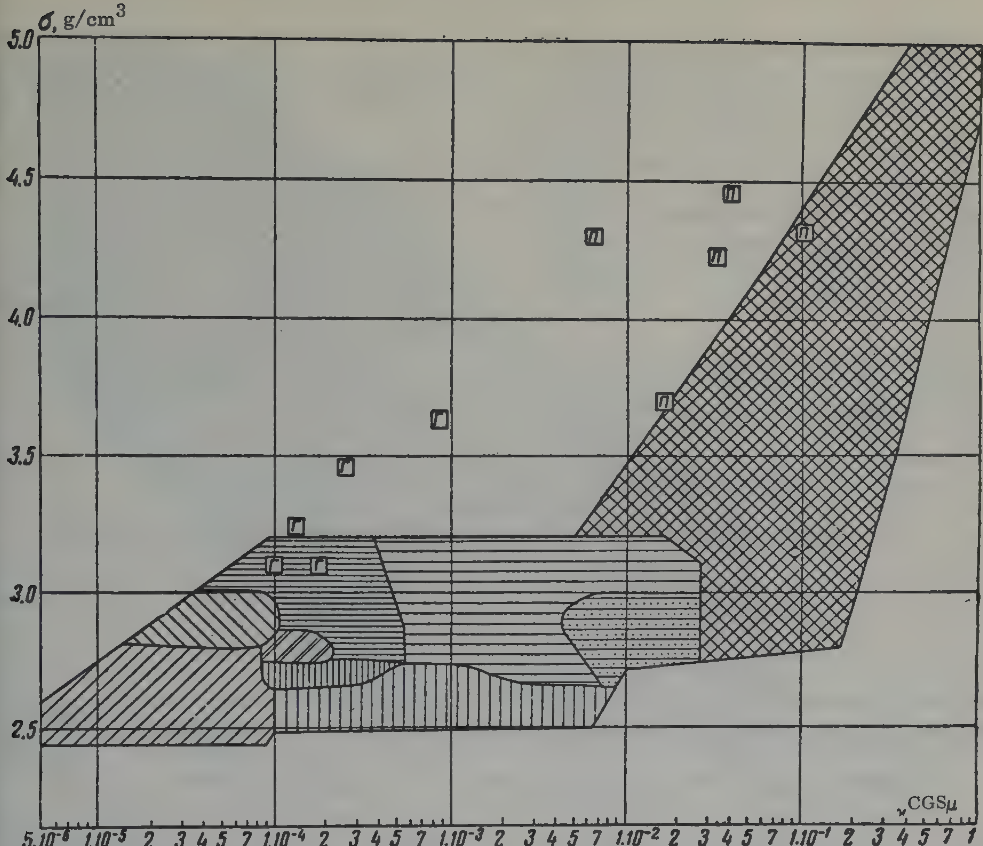


FIGURE 4. Relationships of ϰ and σ values in crystalline rocks from the same regions.

ong the ϰ -axis, the distinctions and the ommunity of the zone configurations and imensions are determined by the ratio of arameters Fp and ϰ n.

In Figure 3 all the zones are located in the ower right half of the diagram between the agonal for H = 100% and the line of H = 0. 1%. s can be seen, the lowest values of parameter pertain to the rocks containing the smallest elative quantity of secondary magnetite nagnetite ores, quartzites and hornfels, hy- rid granites, gabbro-diabases). The highest alues characterize matamorphic rocks con- ining negligible concentrations of dispersed econdary magnetite, effusive analogs of gab- roids containing small segregates of primary rromagnetic material (titanomagnetite), and e hematite ores containing relict magnetite. is readily noticeable that the zones of gab- roids, granitoids, and iron-ore formations ccupy a larger area in Figure 3 than in igure 2, and the zone of granodiorite- neisses appears at the same time to be even iore strictly confined to its proper location etween the hybrid granites and the gneisses.

Thus, a graphic construction clearly illustrates the fact that parameters ϰ n and H characterize not a random but the basic properties of rocks predetermined by their origin and metamorphism. If the value of parameter M is affected most by the composition and quality of the ferromagnetic material (concentration and character of deposition of paramagnetic minerals), then the value of parameter H depends in the first instance on the size of the ferromagnetic grains and the manner of aggregation of the ferromagnetic components with the rock-forming minerals. Parameter H is higher, as the size of the magnetite deposits decreases and as the grouping of these deposits with the silicate minerals is closer. Such a picture is observable, in particular, in basalts and basaltic diabases.

Distinctions in rock characteristics in terms of parameter M and H values also may be illustrated by the difference in the configuration and position of the zone of skarn-type rocks. Thus, if in Figure 2 this zone occupies the extreme left position and is elongated along the line of M = 200-400, in Figure 3 this zone is transverse with respect to the H lines over a

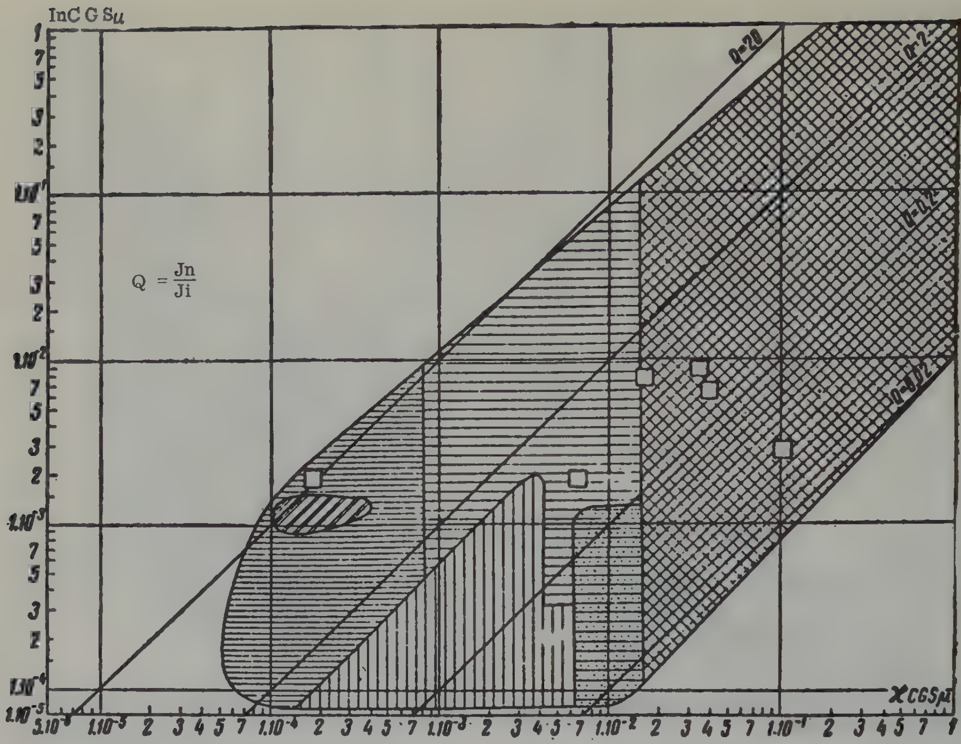


FIGURE 5. Relationship of ϰ and Jn values in crystalline rocks from the same regions.

range of H values from 100% to ~ 20%. The different location of this zone is due to the fact that in Figure 2, parameter M mainly expressed the composition of ferromagnetite minerals (pyrrhotite) whereas in Figure 3 parameter H expresses the relation between the coarse-grained (pyrrhotite) and the fine-grained (secondary magnetite) ferromagnetic bodies. On the basis of the range of parameter H values it is possible to distinguish rocks with distinctly pronounced pyrrhotitic mineralization accompanied or unaccompanied by secondary magnetitic mineralization. Analogous relationships between primary and secondary ferromagnetic metallization may be observed in comparing the other zones indicated in the graphs.

Since the ferromagnetic composition (magnetite, titanomagnetite, magnetic pyrites, etc.) is mainly determined by the content and origin of the rocks containing them (magnetite for granitoids, titanomagnetite for gabbroids, pyrrhotite for several types of metasomatic rocks, etc.), parameter M can be utilized as an objective criterion for the genetic classification of rocks.

Parameter H, which reacts discriminately to the ratio of large and fine ferromagnetic segregations resulting from secondary geochemical transformations, may be used as an objective criterion in determining the nature and degree of rock metamorphism.

The outlined regularity in M and H variations in rocks having different composition, origin, and metamorphism permits us to express the conviction that not only each type, but each variety of crystalline rocks will be given a perfectly definite and specific magnetic and mineralogical characteristic as a result of subsequent detailed MFMA analyses of geological formations.

MFMA parameters are capable of providing a precise definition of the orientation and depth of the metamorphic alterations of ortho- and para-rocks constitutionally similar but differing in origin and metamorphism. For this purpose it is necessary that investigations be continued to provide a more definite specification of the relationships between MFMA parameters and the composition of ferromagnetic segregates with due consideration of their morphology in rocks of different origin having distinctly expressed manifestations of such processes as opacitization, amphibolization, serpentization, and biotitization of ferruginous minerals which are responsible for the generation of a secondary and definite transformation of primary magnetite deposits.

In order to attain these ends use could be ma

t only of magnetic parameters but also of nsity values. Figure 4 shows the relationips between parameters $\varkappa$ and $\sigma$ with respect the same rocks and zones as indicated in gures 2 and 3.

It is noteworthy that the zones of concenation of rocks having specific composition, etamorphism, and genesis as outlined on e basis of magnetic characteristics have not ly lost nothing in terms of specificity and finiteness of graphic expression with the troduction of density characteristics, but ve, on the contrary, gained in over-all vidness in certain cases. If desired it is ssible, for example, to isolate the graniteeisses and acid migmatites possessing the west density values ($\sigma$ = 2.5 - 2.65) in the eiss zone. The highest density ($\sigma$ = 2.70 to 85) is in the gneisses of biotite-sillimanite d biotite-garnetiferous compositions. Bioe gneisses and diorite-gneisses occupy an termediate position. Densities, clearly stinguishable from those of other varieties hybrid granitoids are the grano-syenites = 2.5 to 2.6). The most highly differenated in terms of density and susceptibility observable in iron-ore formations. If, on e basis of density values, one can distinguish e magnetitic ores, magnetitic hornfels, magtite quartzites, and magnetite schists, then, om the magnitude of susceptibility it bemes possible to isolate the magnetite, pyrrhoe, hematite-magnetite, magnetite-hematite, d hematite minerals.

A comparison of Figures 2, 3, and 4 show at ferromagnetic mineralization is characrized by the basic MFMA magnetic paramers and is regularly related to the over-all ineralogic content of the investigated rocks, pressed in density values. The ferruginous rmations having magnetitic and pyrrhotitic mposition have the highest ferromagnetic ineralization. As ferromagnetic concenation diminishes, the iron-ore formations retaining their high density values ($\sigma$ > 3) adually acquire a hematitic aspect.

Among igneous rocks the highest ferromagtic mineralization occurs in olivine gabbro, bbro-diabases, basalts, andesites, pyroxetes, diorites, and hybrid granites. All of ese rocks, depending on their composition, ntain predominantly primary magnetite or tanomagnetite, average-composition rocks - agnetite and titanomagnetite. Secondary agnetitic mineralization is of no significance granitoids. In gabbroids it represents but negligible fraction of the primary magnetite, it in pyroxenites and other ultrabasic rocks may play a substantial role.

In rocks subjected to various stages of etamorphism, primary ferromagnetic etallization gradually loses its importance in giving way to secondary mineralization. In such highly altered and relatively heavy rocks as biotite-garnetiferous and sillimanite-garnetiferous gneisses or amphibolites, only secondary magnetite is to be found, and sometimes pyrrhotite. The presence of maghemite, in addition to secondary magnetite, is possible in certain varieties of gabbro-amphibolites. Consequently, ferromagnetic mineralization reflects the specific conditions of formation and subsequent mineralogical transformations of rocks.

MFMA parameters characterize the individual manifestations and the aggregate totality of ferromagnetic mineralization of rocks and constitute the new reliable criteria of the magnetic and mineralogical state of the substance. Their significance in the development of geological science is obvious, and their practical utilization absolutely indispensable.

In conclusion, we shall discuss Figure 5 in which the investigation of rocks is based on parameters Jn, $\varkappa$ and Q. This construction shows that natural residual magnetization is also related in a definite manner to element composition, i.e. to a definite composition and structural peculiarities of ferromagnetic minerals. In the general case parameter Jn depends on ferromagnetic concentrations: rocks enriched by ferromagnetic minerals possess higher values of residual magnetization. However, this general postulation calls for certain qualifying specifications. For example, rocks with different compositions — even if the ferromagnetic concentrations in them are identical — may have sharply differing values of parmeter Jn and a wide range of parameter Q variations (from 0.02 to 20).

The highest values of parameter Q are displayed by magnetite ores having columnar structure and containing maghemite, olivine gabbro, and hypersthene gabbro-amphibolite (amphibolized norite) with oriented mineralization of secondary magnetite. Low values of this parameter are observable in oxidized varieties of constitutionally different rocks, including the martinized types of basalt found in the Chernigov Boring - the youngest of all rocks examined by us (Devonian). Intermediate values of this parameter typify the hybrid granites, diorites, diorites and gabbro-diorites. Therefore, depending on the composition and content of ferromagnetic minerals, rocks may possess various values of parameter Q.

In speaking of the state of ferromagnetic minerals we mean not only the degree of oxidation but also the character of inclusions. Analysis of polished sections of samples having different values for parameters Jn and Q indicates that the samples containing titanomagnetite with decay structure in the form of a very

dense lattice of very thin ilmenite plates are characterized by higher values of the above parameters as compared to samples containing pure magnetite or titanomagnetite with ilmenite inclusions of irregular form, or in the shape of short and rare plates. It is obvious that parameters Jn and Q also may be utilized for rock characterization.

Thus, MFMA provides an opportunity to discover new, and to define more precisely, already known geological and physical regularities and relationships. As a result of investigations of various types of rocks applying this analysis, a scientifically and practically important postulation is being borne out: ferromagnetic mineralization is regularly related to general mineralization and reflects the peculiarities of origin and transformation of rocks. Rocks of varying composition, genesis, and metamorphism show that their ferromagnetic mineralization has specific characteristics, which are reflected in the variety of compositions, sizes, forms, and in the character of associations of the primary ferromagnetic minerals; in the presence or absence in them of inclusions of paramagnetic minerals varying by composition, size, and shape; in the presence or absence of secondary ferromagnetic mineralization; and in the diversity of its dimensions, shape, and association with different silicate minerals.

MFMA parameters react to the individual or composite manifestations of ferromagnetic mineralization and facilitate characterization of the elementary composition of rocks with consideration for their genetic and metamorphic peculiarities.

The results of rock investigations by means of MFMA open new opportunities for practical utilization of magnetic parameters. The obsolete idea that magnetic properties are of interest allegedly only to those geophysicists and geologists who deal with interpretations of magnetic surveys or exploration of iron deposits should be cast away. As shown above, the magnetic properties should interest, in a very practical way, all geologists, mineralogists, geochemists, and geophysicists engaged in studying the elementary composition of geologic formations.

In particular, MFMA may be recommended for purposes of classification of iron ore deposits, genetic classification of igneous and metamorphic rocks, for geologic mapping of crystalline rocks, metallogenic studies of individual areas and major regions, for elaboration of theoretical and methodological problems associated with the geologic interpretation of geophysical data and studies of magnetization of geologic bodies and minerals, as well as of methods of complex regional geologic and geophysical investigations, for investigations of terrigenous strata containing beds with different but sufficiently intensive ferromagnetic mineralization.

The MFMA method should play a leading role in the work of laboratories dealing with systematic studies of physical properties and elementary compositions of rocks and ores.

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All-Union Scientific Research Institute
Petroleum Exploration
(VNIGNI)
of the Ministry of Geology and
Conservation of National Resources
of the U.S.S.R.,
Moscow

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# THE TECTONICS OF THE NORTHERN PARTS OF PATOMSK UPLAND[1]

by
S. V. Ruzhentsev, and Chang Bu-Chung

The geologic structure of the Patomsk upland long ago attracted the attention of geologists. It is mainly under the influence of V.A. Obruchev's writings that a theory has been developed concerning the presence of a smooth arc of folding within the northern confines of the upland. M.M. Tetyaev (15) explained the bend in the fold structure by the presence of a major anticlinorium which pitched in a northeasterly direction and was responsible for the prevalence of northeasterly trends which determine the closure of the folds. A criticism of M.M. Tetyayev's views will be found in Ye.V. Pavlovsky's paper [12], in which it was shown Tetyayev's constructions are an artificial combination of a variety of Precambrian and Lower Paleozoic structures. Considerable attention is devoted to the northern outskirts of the Patomsk upland in N.M. Chumakov's works [17, 18], in which the Patomsk folded zone is shown to be complicated by two transverse uplifts (Urinskiy geanticline and Modinskaya anticline) which are contemporaneous with the Patomsk zone structures.

Up to this time there is still a considerable divergence of opinion as to the nature of the historical development and mechanism of formation of the geologic structures observable an the outskirts of the Patomsk upland. L.I. Salop [14] identifies the Proterozoic Baykal-Patomsk foredeep as separated from the inner Baykal geosyncline by the Baykal-Vitim uplift which, in the Upper-Proterozoic, was an erosion area from which detrital materials were transported into the adjacent troughs. A generally similar view is held by N.M. Chumakov [17], who distinguishes the Pribaykal foredeep as being at the junction of the Baykal geosyncline and the Siberian platform.

N.S. Zaytsev [7] is inclined to consider only the Precambrian trough as a foredeep, relating the Lower Cambrian deposits to a special relict structure. In the opinion of P. Ye. Offman [11], the Angara-Lena trough is a system of two strictly platform-type syneclises. In advancing his concept of a "pericraton subsidence zone", Ye.V. Pavlovskiy has recently given an original evaluation of the Angara-Lena trough. The specifics of such a zone consist, first of all, of an exceedingly long period of development lasting for many geologic periods.

The stratigraphy of the Precambrian and Lower Paleozoic deposits in the northern and northeastern limits of the Patomsk upland is sufficiently well studied [1-6, 8, 9, 12, 14, 18]. Consequently, we shall restrict ourselves to a brief enumeration of the series (starting from the top).

I. The Patomsk complex (Upper Proterozoic, Riphean, Sinian): Ballaganakhian, Mariinskan, Bol'shepatomskian, Barakunian, Valyukhtinian series, Kullekinian horizon, Nikol'skian and Alyanch-Kholychian series.

II. Lower Cambrian: Zherbinian, Tinnovian varicolored series (Aldanian stage): El'gyanian Tolbachanian, Olekminian, Charskian series (Lena stage); Upper Cambrian: Verkholenian series.

III. Ordovician — Lower Silurian: Ust'kutian series (0); Krivolukian and Makarovskian series ($0_{2-3}$); Meikian series ($S_1$).

From data obtained during the 1958-1959 operations we shall try to give below the development characteristic of the region's principal structures for the different stages of its geologic history.

1. Patomsk and Urinsk Upper Proterozoic (Riphean and Sinian) Troughs.

The thick carbonate-terrestrial deposits in the lower and middle parts of the Patomsk complex accumulated along the northern offshoots of the Baykal-Patomsk upland where they filled the large Patomsk trough which is traceable from the basin of Zhuya River to the

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[1] O Tektonike severnykh chastey Patomskogo Nagor'ya. pp. 37-48.

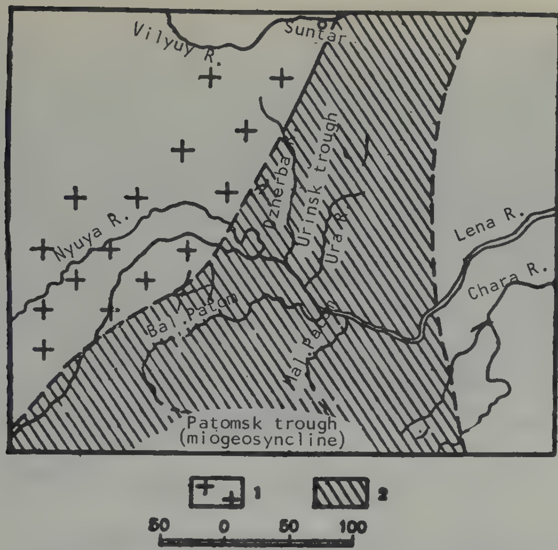


FIGURE 1. Sketch of the location of the principal Upper Proterozoic structures in the northern fringe of the Patomsk trough.

1 - uplifted erosion zones, 2 - accumulation zone of the thick carbonate-terrestrial strata of the Patomsk complex.

iddle course of the Lena. Another trough rinsk), approximately perpendicular to the rmer, extends into the basin of the Dzherba d Ura rivers from the southwest to the rtheast (Figure 1). Both troughs are filled th Upper Proterozoic deposits (Ballaganakh-n, Marinskan, Bol'shepatomskian, Barakun-n, and Valyukhtinian series).

In the deposits of the investigated series identify two types of sections (Figure 2): e northern (lower courses of the Mal. and l. Patom, Ura, and Lena Rivers), and the uthern (upper reaches of the Mal. Patom iver). An extensive development of coarse rrestrial deposits including powerful boulder-nglomerate series (Bol'shepatomskian series), characteristic of the northern sections of e Mariinskian and Bol'shepatomskian series. the upper-course basin of the Mal. Patom outhern series) predominant formations are rbonate (Mariinskian series) or carbonate-gillaceous deposits. The distinctions be-een the northern and southern sections were avily eroded during the period of deposition the Barakunian and Valyukhtinian series. the lower reaches of Mal. Patom along the an and Dzherbedyanka Rivers, carbonate and rbonate-argillaceous deposits interstratified ith quartz- and quartz-feldspathic sandstones d thick beds of underwater slump breccia e developed. Prevalent in the south (Mal. tom River headwaters) are the same car-nate and carbonate-argillaceous deposits. Here, a reduction of sandy material is noted in a number of horizons (the middle section of Barakunian series), and there is no breccia.

It is obvious, therefore, that there was a variation in facies in the deposits of the lower and middle parts of the Upper Proterozoic in the Patom complex. This variation is expressed by the occurrence of the coarsest sediments in the northern part of the trough adjacent to the platform, whereas the fine sediments appear in the sourthern inner part of the trough.

A conclusion may be drawn to the effect that the clastic material which fills the Patomsk trough came from the north, i.e. from the intensively eroded platform regions. The finer sediments, however, are exposed in the upper reaches of Mal. Patom River, closer to the Baykal-Vitim uplift (according to L. I. Salop). Thus, the position taken by this author concerning the erosion of the uplift, which in his opinion represented the source of the terrigeneous material filling the Patmosk trough, appears to be unsupported.

The trough under consideration has a number of characteristic features: linearity, and a specific position between the platform and the inner parts of the Baykal geosyncline characterized by a widespread distribution of volcanic rocks. In approaching the platform, the terrigeneous material becomes even

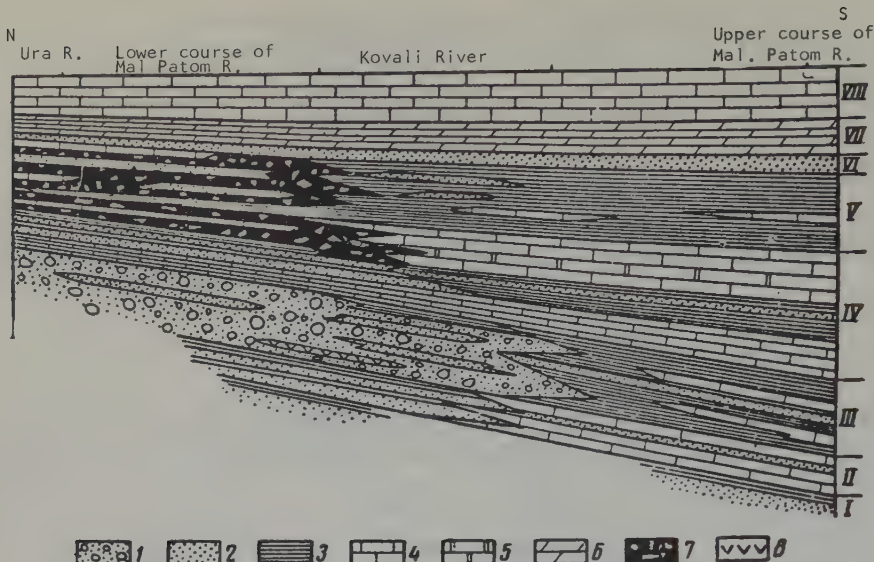


FIGURE 2. Facies profile across the Patomsk Trough.

I - Ballaganakhian series, II - Mariinskian series, III - Bol'shepatomskian series, IV - Barakunian series; V - Valyukhtinian series, VI - Kullekinian horizon; VII - Nikol'skian series; VIII - Alyanch-Kholychian series. 1 - conglomerates, 2 - sandstones, 3 - clay shales and cherty carbonaceous schists, 4 - limestones, 5 - dolomites, 6 - marls, 7 - carbonate and carbonate-argillaceous slump-breccia, 8 - tuffs. Vertical scale - 1:100,000.

coarser and increases in volume toward the edge of the platform which is the obvious source area. These features, and an almost total lack of effusive formations, permits us to consider the Upper Proterozoic Patomsk trough to be a typical miogeosyncline.

The deposits filling the Urinski trough differ almost not al all from those in the Patomsk miogeosyncline. This makes it possible to regard it as a peculiar offshoot of this miogeosyncline projected onto the platform. The first to analyze the morphological caharacteristics of similar structures was N.S. Shatskiy [20]. He has identified the transverse marginal systems genetically and structurally most closely associated with geosynclinal depressions.

Toward the end of the Valyukhtinian series sedimentation, the troughs widened and their shapes were reformed. The nature of sedimentation in them was changed, and as a result, a new independent structure can be identified: the Nyuya trough.

## 2. The Lower Paleozoic Nyuya Trough

The trough in question today consists of a system of two basins: the Berezovsk and Nyuya-Dzherba basins separated by the Urinsk uplift. Both basins are filled with a thick (4300-4400 m) complex of deposits forming the Nikol'skian and Alyanch-Kholychian series belonging to Late Precambrian, Lower and Upper Cambrian Lower Silurian. More than 3000 m of this formation consists of carbonate strata including the Nikol'skian and Alyanch-Kholychian series and Lower Cambrian deposits.

Of great interest is the distribution of thicknesses and facies of Upper Cambrian, Ordovici and Silurian deposits in the Berezovsk basin and the Urinsk uplift (Figure 3). The thickness of Verkholenian series along the lower course of the Bol. Patom River amounts to 350 m according to N.M. Chumakov's data [18], and 314-320 m in the central part of the trough, according to R.F. Gugol' [2]. The uniform thickness of the Ordovician formations is striking. For example, the Ust'kut series in the central section of the trough reaches 220 m in thickness [2], but around the western limb of the Urinsk uplift it is 205 to 220 m thick. The thickness of the Krivolutskian series is 178 m in the first case, and 210-240 m in the second.

The Verkholenian series in the central part of the Berezovsk basin, according to R.F. Gugo is represented by a stratum of redish-brown and greenish clay marls containing subordinate intercalated dolomites and limestones. Bands of coarse-grained siltstones are also encounter According to the data of a recent survey (G.S. Borushko, M.L. Kokaulin), the sections of the Verkholenian series on the western and eastern

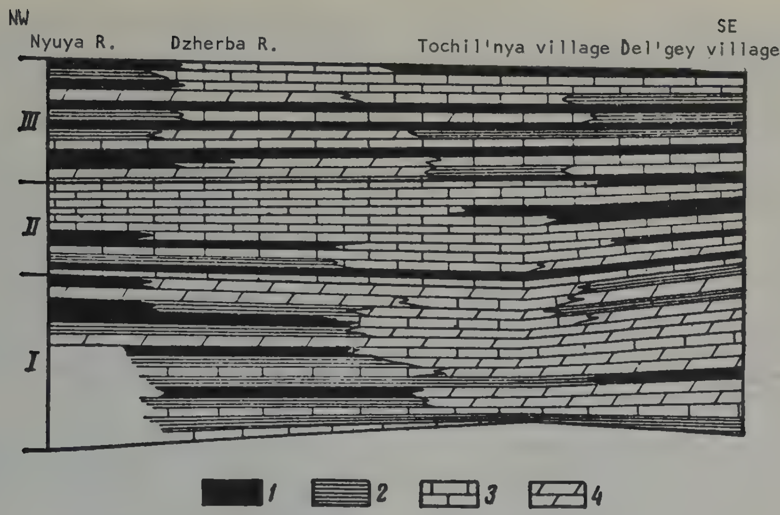


FIGURE 3. Facies profile of the Upper Cambrian and Ordovician deposits of the Nyuya-Dzherba and Berezovsk basins.

Horizontal scale - 1:2,000,000, vertical scale - 1:5,000.
I - Upper-Cambrian, II - Lower Ordovician, III - Middle Upper Ordovician; 1 - sandstones, siltstones; 2 - argillites, 3 - dolomites, limestones, 4 - marls.

slopes of the Urinsk uplift are basically similar. Predominantly developed here are clay marls, argillites, dolomites and limestones, while terrigenous rocks are present in very negligible quantities.

The Ust'kut series in the central part of Berezovsk basin, according to N.S. Zaytsev and N.V. Pokrovskaya's data [6], primarily consists of dolomitized sandy limestones, alternating with polymictic sandstones, siltstones, argillites, and marls. On the eastern limb of the Urinsk uplift the Ust'kutinian deposits are represented by dolomitized, sometimes sandy, algal limestones interstratified with argillites and marls. The sandstones occupy a strictly subordinate position. A generally analogous sequence occurs on the western slope of the uplift, the only difference being that sandstones are absent here altogether.

Thus, we observe that in approaching the Urinsk uplift, whose amplitude exceeds 8 km, from the central part of Berezovsk basin we find almost no facies changes. In certain series (particularly well manifested in the Ust'kut, and to a lesser degree, in that of the Verkholenian series) one notes the smaller role played by terrigenous material as one draws closer to this uplift.

The deduction is obvious. In the Lower Silurian, the Nyuya trough constitutes a major single structure free of internal uplifts which would have separated it into individual basins.

It is interesting to trace the mode of transition between the deposits in the lower and middle parts of the Patomsk complex, on the one hand, and the upper section of the Patomsk complex and the Lower Cambrian formations, on the other. As studies by V.N. Makhayev, L.I. Salop, V.K. Golovenko, and N.M. Chumakov showed, the Valyukhtian schists are related by gradual transition to the Nikol'skian series, whereas the deposits of the Alyanch-Kholychian series are related to the Zherbinian sandstone series of the Lower Cambrian. Under these circumstances, the only method which we could use successfully in our attempt to characterize the Nyuya trough through the various stages of its existence, is the formational method.

During the time when the Upper Proterozoic Patomsk miogeosyncline was in existence the Aldan shield was uplifted and served as an erosion zone. It was not until the end of the Valyukhtinian age that it was partially covered by the sea and a thin bed of quartz and quartz-feldspathic sandstones containing individual intercalations of dolomite was deposited within its limits [5].

The following three formations have been identified by us in the Patomsk miogeosyncline: the lower formation (Ballaganakhian and Mariinian series), composed of alternating quartz and quartz-feldspathic sandstones,

clay shales and, less frequently, limestones; the middle formation (Bol'shepatomskian series) made up by conglomerates, sandstones, cherty coals, and clay shales; and the upper formation (Barakunian and Valyukhtinian series) represented by interbanded limestones, dolomites, clay shales, quartz sandstones and thick beds of carbonate and carbonate-clay breccias.

By the end of Upper Proterozoic (Nikol'skian and Alyanch-Kholychian series) a diversified 900- 1200-m complex of deposits had accumulated in the northern and northeastern outskirts of the Patomsk uplift. The chief characteristic of the strata under discussion is the marked prevalence of various carbonate rocks, including marls, dolomitic marls, fine-grained — sometimes algal and oolitic, sometimes clastic — limestones alternating with sandy limestones. These deposits are classified by us as the lower carbonate formation of the Nyuya trough.

The deposits of Zherbinian series, represented by uniform strata of quartz sandstones containing individual bands of quartz siltstones, are identified by us as the terrigenous formation of the Nyuya trough. The deposits of this formation are 250-300 m thick an and, apparently, already resemble a platform formation.

Higher in the column there is a diversified complex of light-colored, aphanitic limestones limestone shales, dolomites, dark bituminous limestones, interbanded with argillites. This complex we also classify as a terrigenous-carbonate formation of the Nyuya trough (it corresponds to the Lower Cambrian Tinnovian series). The thickness of this formation is about 500 m.

The upper terrigenous carbonate formations in the Nyuya trough correspond to the Lena stage deposits (El'gyanian, Tolbachanian, Olekminian and Charskian series). As a whole, it is distinguished by its considerable facies uniformity and is represented by brown, dark-gray limestones, often oncolitic or stromatolitic, alternating with light-colored dolomites. The formation attains a thickness of 1000-1100 m.

Thus, in the period of the Patomsk miogeosyncline's existence, carbonate-terrigene strata of great thickness were deposited under conditions of intense downwarping. The detrital material was supplied from platform regions which were subjected to intense erosion.

Beginning with the end of Upper Proterozoic, new formations appeared (the lower carbonate, terrigene, and terrigene-carbonate) which marked the disappearance of the Patomsk miogeosyncline and the development of an independent trough (Nyuya). This depression is filled with a thick (up to 3000 m) series of mostly carbonate rocks among which terrigenous and argillaceous formations sometimes played a substantial role. The deposits of the lower carbonate, terrigeneous, and terrigeneous-carbonate formations have many features in common with the Patomsk miogeosyncline deposits (great thicknesses, variegated lithological composition, etc.). Therefore, their identification as formations characteristic for the independent trough must be considered as rather conditional and mainly due to their intermediate position between the platform rocks (variegated and carbonate formations) and the miogeosyncline deposits.

A widening of the trough took place during the same period, with the resultant downwarping involving vast areas of the Aldan shield where a relatively thin (400-500 m) dolomite series was formed. Both in terms of thickness of deposits and in composition, the rocks of both formations are drastically different.

The Lower Cambrian variegated formation in the Nyuya trough still indicates that there must have been considerable down warping in this depression where the deposits are generally twice to three times as thick as those of the Aldan shield. At the same time, one should note a certain leveling out of structural distinctions between the variegated and the older formations.

A still greater lessening of the differences between the deposits of both tectonic zones must have taken place while the upper carbonate formations were being deposited at the end of the Lower Cambrian epoch. The upper carbonate formation in the Nyuya trough acquired the features of typical platform structures. The Nyuya trough area and the Aldan shield differed little from one another at that time as far as tectonic conditions were concerned. The difference was only in the greater degree of warping in the Nyuya depression. As a result, the Nyuya deposits are one- and one-half times thicker than those of the Aldan shield.

On the basis of the enumerated data, the general sequence of changes affecting the formations can be formulated as follows. There was a gradual lessening of the distinctions between the formations of the Patomsk miogeosyncline and the inherited Nyuya trough, on the one hand, and those of the Aldan shield, on the other. This happened against a background of regeneration of the Patomsk miogeosyncline into a special structure of platform type.

Thus, the development of the investigated region in the Riphean (Upper Proterozoic) and Lower Cambrian can be reduced to the


FIGURE 4. Schematic geologic map of the northern fringe of the Patomsk Upland (compiled from materials produced by G.S. Borushko, V.K. Golovenko, .L. Kokaulin, S.V. Ruzhetsev, Chang-Bu-Chung, N. M. Chumakov).

1 - Ballaganakhian, Mariinskian, Bol'shepatomian series; 2 - Barakunian series; 3 - Valyukhtinian series; 4 - Nikol'skian, Alyanch-Kholychian series; 5 - Zherbinian series; 6 - Tinnovian and the variegated series; 7 - Lenian stage; 8 - Upper Cambrian, Ordovician, Lower Silurian; 9 - Deso-Cenozoic deposits; 10 - ruptured zones.

formation of the Patomsk miogeosyncline which, starting at the end of Upper Proterozoic, gradually but rapidly, changed into a peculiar syneclise, marginal with respect to the Baykal geosyncline.

In the light of this discussion it is apparent that the zone of pericratonnal subsidence transcends the concept of the Angaro-Lena depression as argued by Ye. V. Pavlovskiy.

It is true that the Upper Proterozoic Patomsk complex is structurally inseparable from the overlying sedimentary series of the entire Lower Paleozoic. Nevertheless, there exists, in our opinion, a sufficiently sharp boundary between the major portion of the Patomsk complex and the Nikol'skian series. This is manifested in the sequence of formations, as well as in the reconstruction of the shape of the Lower Cambrian trough as compared to the Upper Proterozoic trough. A sufficiently distinct structural boundary also can be traced along the border between the Lower and Upper Cambrian.

The following sequence of formations is characteristic of the formational peculiarities of the various Upper-Proterozoic — Lower-Paleozoic stratigraphic complexes. The lower and middle beds of the Patomsk complex represent the strata of the Patomsk miogeosyncline. The late Precambrian deposits of the Nikol'skian and Alyanch-Kholychian series, and the Lower Cambrian deposits are, apparently, already formations of the platform type. However, judging by their thickness they are not comparable to typical platform-type formations. Finally, the Upper Cambrian (Lower Silurian) deposits are to be classed as typical platform formations. Thus, two historical stages can be specified for the Upper Proterozoic - Lower Paleozoic and the boundary between them is distinct in all respects. These periods are the period of the Patomsk miogeosynclines existence and the period of the Nyuya trough formation. Structurally, the Nyuya trough is far from being uniform, and the history of its development must, in turn, be divided into two stages: the Lower Cambrian and the Upper Cambrian - Lower Silurian. The discussed material is a good illustration for the theory that the zone of pericratonnal subsidences is a complex of distinctly pronounced depressions which have a similar structural plan and which were formed as a result of inherited and protracted development from structures of the geosynclinal type to structures of strictly platform type.

## 3. The Folded Zone of the Baykal Caledonides.

Sedimentation in the Nyuya trough came to an end at the boundary between the Lower and Upper Silurian. By that time there appeared along the northern fringe of the Patomsk upland a wide zone of linear folds which folded the Precambrian and Upper Paleozoic (including the Lower Silurian) formations. There is considerable literature dealing with the age of these dislocations and we shall, therefore, refrain from discussing this problem in greater detail. We shall merely point out that the theory concerning the Caledonian age of the structures appears preferable to us since there is ample evidence pointing to the conformity of Lower and Upper Cambrian deposits [3, 4, 8, 9, 12, 16] and no proof — other than the isolated case described by Ya. A. Shalek [19] — of any major discordances at the Lower-Upper Cambrian contact. In a few instances, an unconformity was noted only with respect to the overlying Verkhnelenian deposits on the beds of the Charskian series [10, 17], but the displacements here are very insignificant.

It is far more difficult to pass a more accurate judgement on the precise time of origin

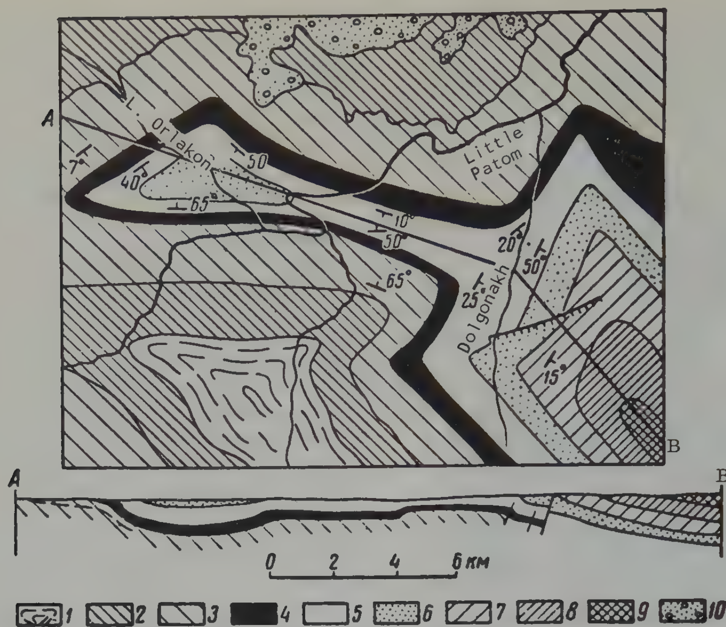


FIGURE 5. Geologic diagram of the middle course of the Mal. Patom basin.

1 - Bol'shepatomskian series; 2 - Barakunian series; 3 - Valykhtinian series; 4 - Nikol'skian series; 5 - Alyanch-Kholychian series; 6 - Zherbinian series; 7 - Tinnovian series; 8 - variegated series; 9 - Lenian stage; 10 - Jurassic.

for the linear folds. The fact is, that it has been definitely established in a number of places in the northern outskirts of the Patomsk upland that sheets, comparable with the traps of the Tungus basin syneclises, have been dislocated in perfect conformity with the country rocks. This indicates in a way that the northern marginal structures are younger. For the time being, there are no data affording a single-value solution of the age problem with respect to the formation here of linear dislocations. In view of this fact we have chosen, in this work, to hold to the generally accepted view about their Caledonian origin. However, in the light of the foregoing discussions it appears to be entirely possible to assign these dislocations to the Upper Paleozoic. Such a point of view was actually expressed in the works of D.K. Zegerbart and Z.M. Starostina [8] and Ye.V. Pavlovskiy [12].

## 4. The Urinsk Hercynian Uplift.

The Urinsk uplift extends from the lower course of the Bol. Patom River for about 100 km in a northeasterly direction. In the upper reaches of the Ura basin, it is covered by the Mesozoic deposits of the Vilyuy syneclise (Figure 4).

The uplift under consideration represents a system of simple, usually box-shaped anticlines, and flat synclines, often almost equidimensional in plan. The most commonly occurring structural types are anticlines with flat and wide arches and flexure-shaped limbs, and synclines with slightly warped bottoms. Narrow flexures having steeply dipping common limbs, separate wide areas with gently sloping layers — this is the typical feature of transverse uplift. Similar structures are widespread in the marginal parts of the Berezovsk and Nyuya-Dzherba troughs (Turuktinsk, Nyuya, Solyankinsk, Khadar, etc.). A study of these flexures helps to clarify the mechanism of structural formation in the Urinsk uplift.

Many cases have been noted where these flexures either turn into major faults along the strike (Dzherbin-Patom flexure — Kuduktinsk fault; Sulyankinsk flexure — Machinsk fault), or are complicated by minor ruptured zones having small amplitudes.

A conclusion may, therefore, be drawn to the effect that the flexure bends are associated with the ruptured zones in the closest possible manner. It is obvious, that such flexures must be considered as fractures transformed in the sedimentary mantle. The planes of these fractures are sometimes exposed at the present surface. The tops of the anticlines and the trough bottoms constitute more or less large


FIGURE 6. Geologic sketch of the Kudutka River basin.

1 - Valyukhtinian series, 2 - Nikol'skian series; 3 - Alyanch-Kholychian series; 4 - Zherbinian series; 5 - Tinnovian series, 6 - Variegated series; 7 - Lenian stage; 8 - traps.

blocks located at different elevations and limited by faults.

Of special interest is the intersection node of the Patomsk folded zone and the Urinsk uplift. The extreme southern structure of the Urinsk uplift is the Zhedaysk anticline. In the Mal. Patom's lower-course basin the linear folds of the Patomsk zone (the Kanskaya, Kurachanskaya, and Chepelyakhskaya folds) join almost at a right angle against the anticline's eastern limb. At the point of their junction with the Zhedaysk anticline, the eastern limb of the latter is disrupted by small-amplitude synclines. The following regularity is observed in the distribution of the Zhedaysk anticline's eastern limb structures: the narrow synclines which complicates the limb of the Zhedaysk fold are located along the strike of the Patomsk zone synclines, whereas the large wide noses revealing the ancient deposits of the Patomsk complex correspond to the anticlines of this zone.

By way of an example let us consider the Kanskaya fold which is an assymmetrical syncline, 5 - 6 km wide, extending for tens of kilometers and similar in every respect to the typical Patomsk zone structures. Its shape changes sharply only in the basin of Dolganakh stream, where its centroclinial terminus appears to be truncated (Figure 5), whereas in plan it has the outline of a somewhat deformed rectangle. Further west of the stream valley in continuation of the Kanskaya syncline there is the narrow (about 1.5 km wide) minor-amplitude Lower Orlakon syncline.

The mode of articulation of the Lower Orlakon and Kanskaya structures is interesting. Essentially the Lower Orlakon syncline is only a narrow and very sharp constriction of the Kanskaya fold. It looks as though a sharp closure in the Kanskaya syncline occurs in the basin of the Dolganakh. Consequently, if one is to consider both folds as a unit, their structure can be represented as a system of two synclines: western (small amplitude) and the eastern (a far greater amplitude), separated by a sharp bend of layers (40° -60° dip to the east-southeast). The azimuth of this slope coincides with the axis of the Kanskaya syncline. The above bend is typical not only for the region being discussed. It has been traced to the north along the Mal. Patom valley and is identified by us as the Malo-Patom flexure, along which the western end of the Kanskaya syncline was shifted upward causing the formation of the Lower Orlakon fold.

Another, no less interesting, transition area from the zone of linear folds to the structures of the Urinsk uplift is the basin of the Kudukta River. Here one distinctly observes the meridionally striking fault (Kudukta) which cuts off the Kudukta left-bank linear folds and bounds, on the west, the series of brachy-structures generally oriented parallel to this

fault (Figure 6). The Kudukta fault is traceable for only 25-30 km. It passes northward from the Bol. Patom River valley into the already discussed Dzherbinsk-Patomsk flexure which bounds the Urinsk uplift on the west. West of the Kudukta fault Lenian-stage deposits and those of the variegated series are prevalent. To the east occur the Alyanch-Kholychian, Zherbinian and Tinnovian series, i. e., the zone of brachy-structures was uplifted (approximately 1000 m) along the fault relative to the zone of linear folds.

Deformation and truncation of the linear folds is also observable south of the Zhedaysk anticline (Kovalinskaya anticline, the Upper Orlakon syncline).

Analysis of the cited examples makes it apparent that the transformation of the original shape of the Patomsk zone linear folds is associated with the Urinsk uplift: 1) the Patomsk zone linear folds and the Urinsk uplift are structures of different ages; 2) the Urinsk uplift was formed later than the linear folds of the Patomsk zone.

The peculiarity of the geologic structure in the basins of the lower reaches of the Bol. and Mal. Patom Rivers, and of the Ura and Dzherba Rivers consists in the widespread occurrence here of sheet traps which ideally repeat the shape of the folds of the country rocks. The youngest deposits — metamorphozed by traps — are Lower Silurian limestones. This, apparently, permits the traps of the described territory to be tentatively correlated with the well-known traps of the Tungus basin.

On the basis of the relation of these intrusions to the principal ruptured zones of the Urinsk uplift an attempt may be made to draw certain conclusions concerning the time of its origin.

The Kudukta fault is one of the basic ruptured zones separating the Urinsk uplift from the linear folds of the Patomsk zone. On the north this fault passes into the large Dzherbinsk-Patomsk flexure. Both the Kudukta fault and the above flexure are the most important dislocations bounding the Urinsk uplift. This is the reason that the problem of structural relationships between the Kudukta fault and the traps is of special interest. Two conclusions could be made: 1) the basic magma does not follow the fault fractures as it is intruded; 2) the Kudukta fault truncates the traps in shifting two parts of the same intrusive sill by 1000 m in a vertical direction.

From the above it is evident that the Kudukta fault, and the west, were finally formed after the intrusion of the traps. Apparently, this position, — with but very slight reservation, can be applied to all other flexures and fractures in the Urinsk uplift, since we have no reason to consider them as being of different age than the Kudukta fault. At the same time, so far we know of no fracture, of which there is an abundance within the limits of the Urinsky uplift, which could be utilized by trap bodies. Hence, the uplift in question must have been fully formed during the period when syneclises existed in the Tunguss basin.

Briefly, the history of the geologic development of the northern fringe areas of the Patomsk upland can be summarized follows: in the Upper Proterozoic (Riphean, Sinian) and Lower Paleozoic, there existed here a number of downwarps (the Patomsk miogeosyncline, Nyuya trough) characterized by distinctly expressed inherited development. We are inclined to share Ye. V. Pavlovskiy's opinion that the depressions referred to above should be identified as a single major structure — a zone of pericratonnal subsidences.

The development of the troughs in question came to an end toward the end of the Lower Silurian when a wide zone of linear folds was developed around the Patomsk upland from the north in the form of a smooth arc. The Urinsk uplift was formed in the Upper Paleozoic and its structure was superimposed on the linear folds of the Patomsk zone.

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Geological Institute of the
U.S.S.R. Academy of Sciences,
Moscow

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# AGE AND STRATIFICATION SEQUENCE OF DEPOSITS IN THE UPPER PART OF THE KAR-TAU SERIES IN THE SOUTHERN URALS[1]

by
Yu. R. Bekker

The article describes the stratification sequence of the Min'yar and Ukian deposits of the Karatau series of the Bashkir geanticline. The data given permit these deposits, and consequently the entire Karatau series, to be considered as a part of the Proterozoic formations.

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The upper deposits of the Karatau series in the Southern Urals are still inadequately studied. Meanwhile, a detailed investigation of these formations provides a wealth of material with which to consider a number of cardinal problems relative to the geology of the Urals.

## 1. The Min'yar Series

In the section of the ancient Ural formations the Min'yar series lies between the overlying Ukian and the underlying Inzer deposits. In the Southern Urals this complex was studied by O.P. Goryainova, E.A. Fal'kova [5, 6], H. Dingel'shtedt [8], K.A. L'vov [11], A.I. Oli [15], A.P. Tyazhev and S.M. Domrachev [..].

However, "attempts to divide the Min'yar formations into a set of beds traceable over considerable areas have failed so far" [16]. This fact is attributable to the view which was generally held until recently that Min'yar deposits are lithologically uniform, pure carbonate sediments in which terrigenous rocks play no significant part. In the meantime, investigations of these rocks showed that key horizons, covering large areas, can be identified in them.

I distinguish two formations in the Min'yar deposits: the Minki and the B'yanki strata (Figure 1).

The deposits of the lower Minki stratum, though poorly exposed, are apparently widespread in the Southern Urals. Outcrops of these rocks can be observed along the Yurezan' River near the railroad siding at Minki (from which the name of the stratum was derived), along the Sim River in the vicinity of the railroad siding at B'yanki, along the Revat River west of Urman-Revat settlement, along the Belaya River near the village of Muradymovo, and in a number of other places.

In the basin of Sim River, near the settlement of Min'yar, a well exposed section of the Minki stratum reveals two beds (from top to bottom): 1) a bed of clearly stratified limestones with thin platy structure and dolomites; and 2) a bed of algal dolomites.

In the lower section of the Min'yar series the lower beds grade into the Inzer deposits without exhibiting signs of erosion. This type of transition is traceable near the Kal'tyarau River (Belaya River basin) as described in the following section.

The Inzer Series: 1. A bed of alternating greenish-grey, less frequently bordeau-colored (red) sandy shales containing subordinate intercalations of grey siltstones. The proportion of clay shales increases in the upper section of the series Noteworthy is the considerable amount of chlorite and almost total lack of glauconite — a mineral which is very typical of these rocks in the western sections of the Inzer series. The shales are plicated and more than 50 meters thick.

The Min'yar Series: 2. Pinkish, coarsely-crystalline limestones containing greenish clay flucans and quartzite veinlets are superposed sharply upon the Inzer shales described above. The azimuth of dip is 90° < 34°. The thickness of the limestones is 20 cm.

3. A bed of interstratified white, greenish-grey thin-platy-structure limestones containing subordinate intercalations of greenish-grey

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[1]Vozrast i posledovatel'nost' naplastovaniya otlozheniy verkhney chasti Karatauskoy Serii Yuzhnogo Urala. pp. 49 - 60.

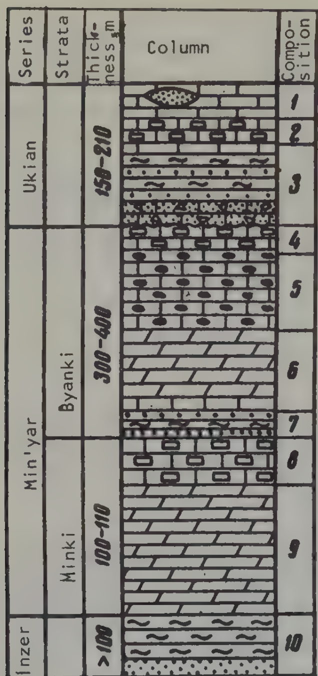


FIGURE 1. Stratigraphic column of the upper section of the Karatau series in the Southern Urals.

1 - dolomites, limestones with sandstone lenses; 2 - algal dolomites; 3 - detrital limestones, dolomites, siltstones, argillites; 4 - algal dolomites, limestones with medium platy structure; 5 - layered dolomites, flinty limestones; 6 - coarse platy limestones, dolomites; 7 - siltstones, argillites; 8 - algal dolomites; 9 - thinly-layered dolomites and limestones; 10 - glauconite sandstones, argillites.

marls and argillites. The clay content diminishes upward along the section. The thickness of this bed is 3.4 m.

4. Medium platy-structure limestones, light-grey at the bottom and grey, above. Veinlets of quartzite, sutures and styloitic structures are often observed in the limestones, which exceed 10 m in thickness.

Similar contacts between the Inzer and Min'yar series is also typical of other sections (Min'yar settlement), where minor ferrugination may sometimes be observed in the near-contact zone.

Peculiar to the lower layer deposits of the Minki stratum is the presence of sutured and stylolitic surfaces filled with a ferruginized pelitic substance. Occasionally thin veinlets of calcits are observed in these rocks. In sections having particularly densely distributed calcite veinlets the rock acquires a pseudo-conglomerate aspect.

The mineralogical composition of the Min'yar series carbonate rocks was studied by the method proposed by L.G. Berg, which was given the name of thermal-volumetric-quantitative phase analysis. The principles involved in this method are discussed in detail in L.G. Berg's works and in an article written jointly by T.Ye. Biryukova, I.V. Yevseyeva, I.I. Ivanova, Ye.P. Levando, and O.I. Nekrasova [2].

The results of the thermal-volumetric-quantitative phase analysis,[2] in conjunction with the data obtained from microscopic examination involving color reactions, make it possible to identify two varieties of carbonate rocks in the Minki stratum: dolomitic limestones and dolomites.

The dolomitic limestones are grey and dark-grey in color and contain dolomite (up to 25%) and an insignificant amount of insoluble residue (2.4%). Thermal analysis revealed the presence of siderite and rhodochrosite occurring as admixtures usually not exceeding 1%. The presence of (0.01-0.03%) strontium in these deposits was detected by spectral analyses.

The Minki stratum dolomites are brown-grey in color and manifest an uneven tubercle-like bedding plane. The dolomites are more macrocrystalline than the limestones. Veinlets of calcite are observed in them. This, probably explains the rather high content of calcite established by quantitative thermal-volumetric analysis in these rocks. The proportion of magnesite in the Minki dolomites ordinarily does not exceed 7%.

Carbonate rocks in the top layer contain cylindrically shaped stromatoliths having a maximum diameter of from 2 to 3 cm. They are almost at right angles to the bedding plane of the rock and are "enveloped" by a clayey substance containing a high percentage of glauconite. The algal layer rocks, which seem to be less abundant than the underlying deposits, terminate the Minki sequence of the Min'yar series. The apparent thickness of the Minki stratum in many sections does not exceed 100 m, with the top algal layer usually accounting for some 5-8 meters.

The B'yanki stratum is the thickest and most exposed member of the Min'yar series, covering a considerable area in the Southern Urals from the basin of the Ay River in the north to the basin of the Belaya River in the south. In the stratigraphic section of this stratum near the B'yanki siding on the Sim River the following beds (from bottom up) can be identified:

[2] This analysis of the carbonate rocks of the Min'yar series was made by T.Ye. Biryukova.

1) argillites and siltstones; 2) massive dolomites; 3) dolomites containing chert; 4) limestones with medium platy structure and dolomites.

The lower layer of the B'yanki formation is exposed only in the basin of the Sim River. Here, in the vicinity of the B'yanki railroad siding, overlying the Minki limestones are greenish-grey argillites interbedded with light-grey, thin-plated quartzose siltstones containing glauconite. The argillites predominate in the lower part of the section, the siltstones, in the top.

The greenish-grey argillites of this formation contain small quantities of quartz terrigenous material and large round grains of authigenic glauconite. According to the data of thermal, electron-diffraction, and electron-microscopic investigations, argillite fraction particles measuring less than 0.001 mm occur mainly in the hydromicaceous component. The heating curve of the argillites is characterized by three endothermic reactions at 130°, 630°, and 940° temperatures and one exothermic reaction at 1000°. Electron-diffraction studies produced the following unit-cell parameters f or the argillites in question: a = 519, b = 8.97, c = 20.0 kX, $\beta$ = 95°. A two-layer period and a rather low degree of structural perfection characterize the hydromicas under consideration. Electron-diffraction analyses have revealed the presence of elongated, sharply delineated scales of glauconite and fragments of kaolinite contaminating these argillites.

The siltstones are light grey in color, are of the thin-layered quartz variety and contain large, whitish grains of glauconite. Apart from the prevalent quartz grains, particles of plagioclases and glauconite. Apart from the prevalent quartz grains, particles of plagioclases and quartzites were found in the clastic material of these rocks. The clastic material is fairly well sorted out much less rounded. The accessories are zircon, chromite, olivine, and magnetite. The cement is mixed: carbonate, quartzose, and occasionally sericitic.

The observed thickness of the terrigenous layer in this section is 35 m.

Rocks of this formation were found in the estuarine zone of the Min'yar River in the same position of the stratigraphic column as the Min'yar series. Here, in the lower sectionsof this stratum was found an intercalation of ferruginized oölitic limestones containing significant amounts of terrigenous quartz material. The oölites are composed of carbonaceous ferruginized material and are 5 mm in diameter.

The presence of oölites in the carbonate rocks of the Min'yar series is a matter of decided interest. According to L. Cayeux's [25] and D. V. Nalivkin's [14] data oölites have not been known to occur in Precambrian carbonate rocks. However, in the Karatau series on the Western slope of the Southern Urals, oölitic limestones are fairly conspicuous. Apart from the mentioned stratum, oölitic limestones also are found in the deposits of the Subinzer series overlying the Ukian formations (Figure 2).

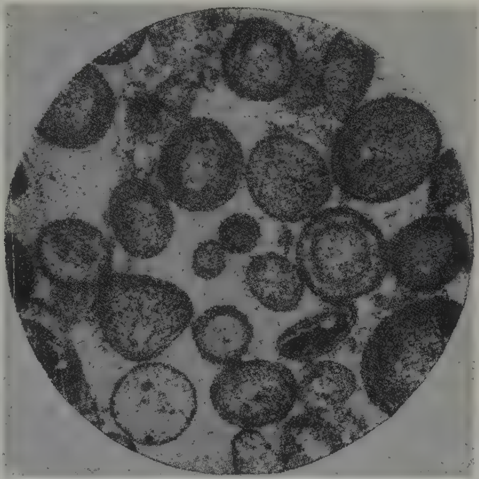

FIGURE 2. Oölites from the Ukian deposits in the Inzer basin.

(Nicol prisms are parallel; 32x).

It should be noted that intercalations of "roe-type" (oölitic) limestones occur in the Subinzer series, in which the oölites are associated with spherulites.

Thus, conditions favorable to the formation of oölites repeatedly occurred, not only in the Paleozoic, but also in the Proterozoic.

In contrast to the discussed, usually poorly exposed terrigenus deposits, the massive dolomites overlying the layer of the B'yanki formation produce spectacular cliffs. These dolomites usually occur in the sections of the Min'yar series in the Ay, Yurezan', Sim, Inzer, Zilim, and Belaya rivers basins. The massive dolomites are brownish-grey in color and mottled with reddish spots. Dolomites with conchoidal structure and limestones with thin, platy structure occur in them as intercalations. Stromatolites of the Collenia genus in certain places constitute the rock-forming organizms in these deposits. Individual sections show thin bands of dolomitic breccia subordinate to the massive dolomites.

According to the data of quantitative thermal-volumetric phase analysis these rocks are mostly composed of dolomite (84.7%), with calcite, siderite, and smithsonite occurring as admixtures. The dolomite is macrocrystalline, individual crystals being as long as 2 mm. The proportion of insoluble residue in the dolomites is about 4%. The thickness of the massive dolomite bed does not exceed 200-250 m in many sections.

Upward in the section, the massive dolomites gradually change into a bed of dolomites containing flint. These dolomites make a well-exposed key horizon traceable in the majority of the Min'yar series sections in the Southern Urals. Bedrock outcrops of this horizon can be observed along the Ay River, in the area of Vanyashkino and Sikiyaz-Tamak villages; along the Yurezan' River, near Vyazovaya station and the settlement of Ust'-Katav; along the Sim River, near the Min'yar and Sim factories; along the Ray and Meneyka Rivers (Inzer River basin), and in several other localities.

The carbonate rocks containing the flinty concretions are represented by grey, light-grey dolomites and very rarely, by limestones.

The dolomites are microcrystalline, locally recrystallized, contain numerous calcite veins, and a small proportion of insoluble residue (3.4%). A small quantity of siderite was revealed in these rocks by quantitative-thermal-volumetric phase analysis.

A study of the Min'yar series flints permitted us to identify the nodule and vein forms of silica segregation. The former is particularly characteristic of the rocks of the discussed horizon. Among the concretionary siliceous formations in this horizon, one can distinguish layer-type, lenticular concretions, and flint nodules.

The thickness of the siliceous concretion layer is very irregular. In places it attains 20-30 cm, but 30-40 m further along the strike it drops to 2-3 cm and even to zero - in flint lenses. Occasionally one layer splits into two or three separate thinner layers. At individual outcrops, however, it was possible to trace the flint layers extending without substantial variation in thickness for 80 - 100 m along the strike.

The flint concretions are, probably, the most commonly occuring form of silica deposits in the Min'yar series. Their shapes are very diversified. Most cross-sections are ellipsoidal and spherical and, on the bedding planes, look like intricately uncoiled, knotty rope. Siliceous concretions of cylindrical form (about 10 cm in diameter) also are found in a vertical position.

The concretions are usually grey, sometimes dark-grey and unevenly colored, and consist of cryptocrystalline silica. Individual sections reveal the preferential distribution of flints, lighter varieties gravitating toward the lower, the darker - towards the upper, parts of the horizon under consideration. In places, the relationship between the color of the flints and the enclosing rocks is apparent. For example, light-color flints frequently predominant in light-grey dolomites. However, both light and dark flints are found in the dark-grey carbonate rocks. Beds of siliceous substance containing a significant amount of carbonate material are found in places where the concretions are in contact with the enclosing rocks. Often the groundmass of the cryptocrystalline flint contains individual idiomorphic rhombohedra of dolomite. Widely distributed throughout the concretions are veinlets containing quartz in the center and chalcedony on the periphery.

Carbonate rocks containing flint concretions often display well pronounced layers. This makes it possible to study the relationship between stratification and the shapes of the siliceous concretions. We made such a detailed study of cliff outcrops in the basins of the Yurezan' and Sim Rivers. These investigations disclosed that in the majority of cases (55-65%) the concretions clearly followed the contours of the layers. Only a small part of the concretions (10-15%) cut across the interbedded layers. For concretions embedded in thick unstratified dolomites, such a relationship could not be established. There were instances where the flint concretions were on the uneven bedding plane of the dolomites. As may be seen in Figure 3, the flint rocks faithfully repeat the irregularities of the bedding and exhibit the same wavy upper surface.

The data on the relationship between the shape of the flint concretions and stratification attest to the fact that most flint concretions in this case was formed concurrently with sedimentation.

During the lithification process there was a subsequent shift of the silica and a few of the veinlets and siliceous concretions which now cut across the layers, were formed.

It should be noted that syngenetic and diagenetic concretions can not be distinguished either macroscopically or microscopically. Their identical composition once again indicates that their formation is associated with a redistribution of an identical portion of silica.

Small stringers of flint are observed in the silica bed itself and in a considerably smaller amount in the overlying and underlying layers. Consequently, they have no important stratigraphic significance.

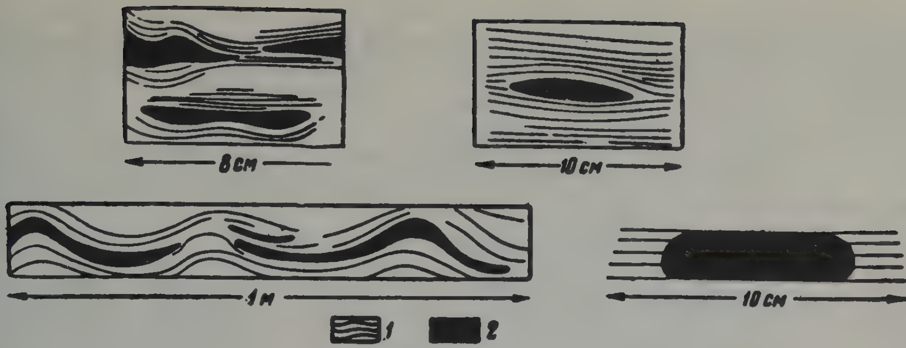


FIGURE 3. Relationship of the shape of flint bodies to the stratification of the carbonate rocks of B'yanki series.

1 - stratified limestones; 2 - flint bodies.

Because there are no organic remains having ica skeletons in the Min'yar deposits, it ust be assumed that the silica here is of in- ganic origin and must have been transported o the marine basin of this period from the jacent uplands.

In concluding the review of the lithological aracteristics of this horizon, it is important emphasize the fact that the silica concre- ns in Min'yar series occupy a definite atigraphic position. This is indicated both direct stratigraphic study and by the data the lithology and the conditions under which se concretions were formed. The dolomites ntaining layered and lenticular concretionary gregations of silica in the Min'yar series nstitute a reliable key horizon permitting identification of sub-siliceous, siliceous, d supra-siliceous layers even when the ex- sure is poor.

In the upper part of the Min'yar series in Yurezan' and Sim river basins dark-grey gal and medium-platy and algal dolomites d limestones were found. Here C.N. Dom- chev discovered some problematical re- ains of Fistulipora. The thickness of these posits does not exceed 50 m and varies con- lerably from section to section because the nsgressive deposition of the overlying Ukian ries.

## II. The Ukian Series

The terrigeneous-carbonate rocks of the ian formation are unconformably overlain the upper bed of the Min'yar series, dis- ssed earlier. First, these deposits were ferentiated and described layer by layer S.M. Domrachev near the Min'yar works d on the Uka River (Sim basin). The Ukian ries is located in these sections between the nally characterized Devonian deposits and the Min'yar rocks. The Ashinian deposits which ordinarily occur in this interval of the Paleozoic sequence are absent here. In view of this fact, S.M. Domrachev assumed that the series he identified was a facies analog of the Ashinian deposits. This point of view was later shared by A.I. Olli [17] and a few other geologists of the Southern Urals Geologic Administration. The same views were also reflected in a collated study by S.G. Sarkisyan and G.I. Teodorovich [19].

My geologic survey in the Sim river basin and adjacent regions permitted me to establish the extensive regional distribution of the Ukian deposits in many of the sections of the ancient formations in the Southern Urals, for example, in the oil pipeline trench on the western limb of Suleymanovskaya anticline, at the watershed of the Yurezan' and Minka Rivers, along the Yurezan' River near the settlement of Ust'-Katav and Limonovka village, along the Sim River in the vicinity of the Sim works; further south along the Rau River (Inzer basin), Basa, Meneyka, Revat - west of the settlement of Urman-Revat, along the Belaya River near Krivaya Luka.

Two beds, interconnected by gradual transgressions, can be distinguished in the majority of the Uka deposit sections.

The lower bed consists of a rather diversified series of rocks including grey and light-grey siltstones, green argillites, clastic and oölitic limestones, ferruginized dolomites, and ash-grey marls. The Ukian sequence usually begins either with conglomerates containing pebbles of the subjacent carbonate rocks, or with ferruginized siltstones.

The siltstone clastic material is represented by well-rounded but poorly sorted quartz grains (80-90%) containing an insignificant admixture

Table 1

| Number in sequence | Name of minerals | Content of minerals, in %: Min'yar station | Sim station | Ust'-Katav | Average |
|---|---|---|---|---|---|
| 1 | Pyrite | — | — | 2,1 | 0,7 |
| 2 | Martite | — | 0,3 | — | 0,1 |
| 3 | Hematite | 90,4 | 92,5 | — | 61,0 |
| 4 | Limonite | RT[1] | RT | 54,1 | 18,0 |
| 5 | Ilmenite | RT | 0,3 | 2,1 | 0,8 |
| 6 | Rutile | 0,3 | — | 0,4 | 0,2 |
| 7 | Anatase | RT | — | — | RT |
| 8 | Leucoxene | — | — | 1,3 | 0,4 |
| 9 | Chromite | RT | 0,9 | 8,5 | 3,1 |
| 10 | Chromopicotite | RT | 0,3 | 0,8 | 0,4 |
| 11 | Magnetite | RT | RT | RT | RT |
| 12 | Zircon | 4,0 | 1,5 | 22,6 | 9,4 |

| Number in sequence | Name of minerals | Content of minerals, in %: Min'yar station | Sim station | Ust'-Katav | Average |
|---|---|---|---|---|---|
| 13 | Monoclinic pyroxene group | 1,3 | 1,8 | 0,4 | 1,2 |
| 14 | Olivine | 1,0 | 1,2 | 4,3 | 2,2 |
| 15 | Garnet | 1,7 | 0,9 | 3,0 | 1,9 |
| 16 | Epidote | RT | — | — | RT |
| 17 | Tourmaline | 1,0 | 0,3 | RT | 0,4 |
| 18 | Monazite | RT | — | RT | RT |
| 19 | Glauconite | RT | RT | RT | RT |
| 20 | Mica | 0,3 | — | 0,4 | 0,2 |
| | Output of concentrate in grams per cu. m. of rock[2] | 27,4 | 26,6 | 8,0 | — |

[1] RT - rare
[2] Synthetic concentrates were obtained by crusing lump samples weighing about 10 kg and subsequent washing out of heavy fraction minerals.
NOTE: Comma represents decimal point.

of plagioclase particles. Glauconite usually is the principal component of Ukian siltstones. The rock cement is basal. Its composition is mixed: sericitic and carbonaceous.

The following heavy fraction minerals were in the siltstones: pyrite, martite, hematite, limonite, ilmenite, rutile, anatase, leucoxene, chromite, chromopicotite, magnetite, zircon, monoclinic pyroxene, olivine, garnet, epidote, tourmaline, monazite, glauconite, mica.[3] The percentage values of these minerals are shown in Table 1.

Noteworthy is the increasing content of accessory minerals in the basic and ultrabasic rocks (olivine, chromite, chromopicotite) eastward from the Min'yar works (1%) and Sima settlement (2.4%) toward the Ust'-Katavskiy works (13.6%). Such percentage variations in these components, apparently, indicate that the clastic material in the Ukian deposits was transported from the island uplands in the east which consisted of basic and ultrabasic rocks.

The detrital sediments in the clastic limestones contain pebbles of microcrystalline dolomites, pelitomorphic micro- and macro-crystalline limestones, and silt-size quartz grains. Carbonate rock pebbles in the clastic limestones attain a size of 5-8 cm. The amount of insoluble residue in these rocks, according to data from a single determination, is 5.7%. Calcite, with occasional strong ferruginization, is the cement in the clastic limestones.

The deposits of the lower formation gradually merge into the basically carbonate overlying rocks which complete the Ukian series section. Good outcrops of these rocks can be observed along the Basa River near the settlement of Kulmas, as well as in the region of the Ust'-Katav and Min'yar works. Distinguishable among the carbonate rocks in the upper section of the Ukian series are light-grey dolomites and grey limestones. Apart from dolomite (79.4%) and secondary calcite (15.9%), the presence of magnesite (2.2%) and siderite (0.4%) was revealed in the light-grey varieties of these carbonate rocks by quantitative-thermal-volume phase analysis.

The grey limestones may be more correctly referred to as dolomitic limestones since, according to thermal analyses, they were found to contain a significant amount of dolomite (26.2%).

Lenses of light-grey friable feldspathic sandstones occur in the upper formation of the Ukian series as seen in individual sections along the Sim and Yurezan' Rivers. The mode of deposition of these rocks is very unusual. The sandstones usually fill 1-1.5-m wide pockets in the carbonate rocks. This deposition of sandstones, apparently, results from the moving of terrigenous material in connection with the processes

[3]Determinations made by the Mineralogical Laboratory of the All-Union Scientific-Research Geologic Institute's (VSEGEI) central expedition.

of ancient karst formation. This theory seems especially probable because occasionally undisturbed, primary, sheet-like or lenticular bedding is observed in the sandstones.

A comparative study of the Ukian, Min'yar, and Ashinian deposits shows that the composition and the organic remains in the Ukian formations display a number of features common to the Min'yar rocks and rather sharply different from the deposits of the Ashinian series. In view of this fact, the supposition concerning the coetaneousness of Ashinian and Ukian deposits must be based on a detailed stratigraphic analysis of the sections.

Investigations carried out in this direction indicate that the Ukian formations lie, with a small break, on the flint and alga-B'yanki carbonate rocks of the Min'yar series and in the basins of the Yurezan' and Inzer Rivers are covered by Ashinian series, and in the basin of the Sim River — by Devonian deposits. Of particular interest are the sequence relationships between the Ashinian and Ukian deposits as they can be observed in the outcrops near the settlement of Ust'-Katav on the Yurezan' River. A generalized description of this section is given below (up from the bottom).

Min'yar series. 1. Massive grey dolomites belonging to the upper part of the Min'yar series containing globular algal formations 5-7 cm in diameter. Total thickness of the bed - about 10 m.

2. Dark-grey and grey limestones, with medium platy structure, and dolomites, forming a 15-meter layer.

Ukian series. 3. Clastic limestone containing gravel and the flattened pebbles of the underlying carbonate rocks. Total thickness, 36 cm.

4. Dark-grey ferruginized detrital or organic limestones, mottled, reddish, locally dark-grey dolomites alternating with grey siltstones and argillites. A layer-by-layer description of this 120-130 m section was prepared on the basis of small bedrock outcrops and mine workings.

5. Massive algal limestones and dolomites, the upper part containing lenses of feldspathic-quartz sandstones which, on cursory inspection, are hardly distinguishable from the enclosing dolomites. Thickness, 85 m.

Ashinian series. 6. Conglomerate with dark-grey flint pebbles (70 to 75%), dolomite (10 to 15%), quartzite and quartz (15 to 20%). The clastic material in the conglomerate is fairly well rounded. The average roundness factor, determined by Wadell's method, is 0.48 for the flint pebbles. The layer is 10 cm thick.

7. Green-grey argillites, containing intercalated siltstones. The observed thickness is about 15 m. Higher, after a thin meadow are interval, on the slope there are exposures of Uryukian gravel conglomerates belonging to the Ashinian series which contain quartz, feldspar, and flint pebbles.

Thus, in the section near Ust'-Katav the Ashinian deposits overlap transgressively the Ukian series. A similar stratigraphic position is occupied by the Ukian series in other sections of the Bashkir anticlinorium (basin of the Inzer and Bas Rivers). In these sections oölitic limestones are occasionally observed in the Ukian series. In these limestones L. V. Khmelevskaya [21] found the remains of annelides in the Sim River basin.

In some places the Ashinian formations also lie unconformably on the Min'yar deposits. For example, in the section near Sikiyaz-Tamak village on the Ay River, Ashinian sandstones overlay the flint dolomites of the B'yanki formations of the Min'yar series.

The above data on the occurrence, composition, and stratigraphic position of Ukian rocks permit us to reject as unsubstantiated the assumption that the Ashinian and Ukian deposits are coetaneous. In retaining the previous designation, the author of this article interprets the stratigraphic position of Ukian deposits in a different way, considering them as an independent formation in the Karatau series of the Southern Urals. The deposits of Ukian series begin a new cycle of sedimentation.

The Min'yar and Ukian deposits were formed in a fairly wide shallow-water marine basin which formerly covered a considerable area of the western slope of the Urals. These deposits were identified both on the western and eastern slopes of the Bashkir geanticline, with the eastern sections of the Min'yar deposits of the western fringe of the Bashkir anticlinorium characterized by great thickness and absence of noticeable facies alterations. This fact justifies the assumption that the marine Min'yar deposits covered the area of the present-day Bashkir anticlinorium and were later eroded (Figure 4).

East of the Min'yar basin, in the recent Ural-Tau zone, there were a number of base-leveled, possibly insular, uplifts. The erosion of these structures was responsible for the formation of a considerable proportion of the clastic material contained in the Min'yar and Ukian deposits.

## III. Age of the Karatau Series

The age of the Karatau series, in particular of the Min'yar and Ukian deposits, is still one of the most debatable and essential problems of

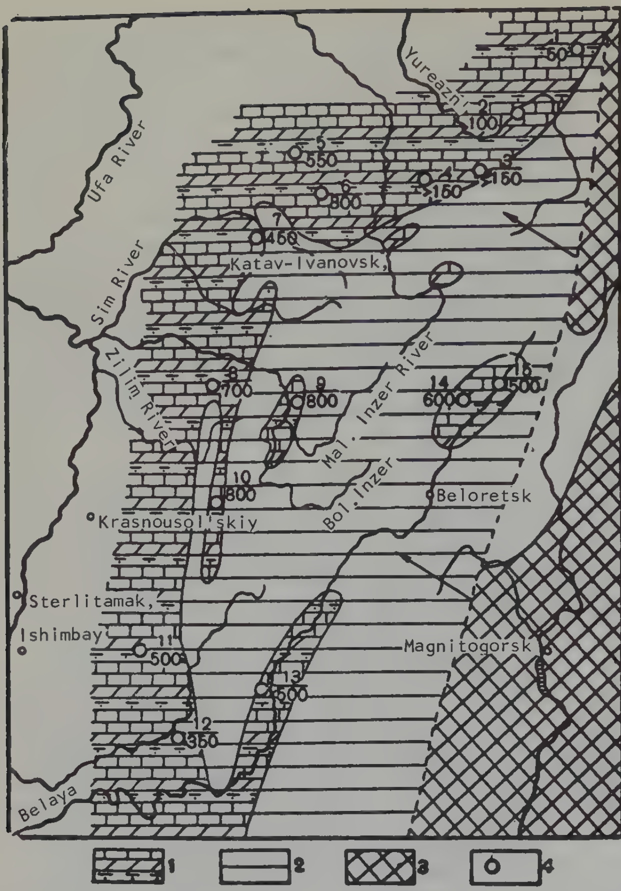


FIGURE 4. Schamatic Lithological Map of the Min'yar an

FIGURE 4. Schematic Lithological-Facies Map of the Min'yar and Ukian deposits in Bashkir geanticline.

(Scale, 1:2,500,000).
1 - distribution area of shallow-water marine deposits; 2 - area of presumed distribution of marine deposits; 3 - Base-leveled peneplain; 4 - the numerator indicates the section number, the denominator - the thickness of deposits.

Ural geology. Different authors assign the Min'yar series to the Proterozoic [3, 4, 23, 24], to the Sinian [20], and to the Cambrain [5, 6, 13]. The Ukian series was considered by S. M. Domrachev [7] as contemporaneous with the Lower Devonian and Eifelian deposits [22]. N. G. Chochia [22] correlated these formation with the Silurian, and the author of this article tentatively assigned them to the Lower Cambrian.

With the view to finding a more definite solution of these problems I have paid particular attention in my field operations to the layer-by-layer collection of fauna, gathering samples for spore analysis, and to the determination of the absolute age of the rocks by the argon method in terms of glauconites. Despite thorough search I failed to collect any identifiable faunal remains in the Min'yar and Ukian deposits.

A fairly large collection of assembled stromatolites was sent to A. G. Vologdin, but has not yet been monographically classified. According to A. G. Vologdin's preliminary report, the collection has revealed well-preserved products of Cyanophycean life activity, similar to the analogous formations found in the Cambrian and Proterozoic of the Siberian platform, but still unrecorded in the literature.

Spores were identified both in the Min'yar and in the Ukian deposits.

In the argillites of the terrigeneous horizon of the B'yanki stratum (in the vicinity of the settlement of Min'yar), I. N. Solomina was able to identify the following spores: Myctero-ligotriletes marmoratus Tim., Bothoroligotriletes exasperatus Tim., Trachyoligotriletes incrassatus (Naum.) Tim., T. nevelensis Tim. T. planus Tim. The complex of these spores differs from the Inzer series spores by the lack of the characteristic Tiloligotriletes asper Tim forms.

In the Ukian argillites, I. N. Solomina discovered a more diversified complex of spores: Leioligotriletes mimitissimus (Naum.) Tim., L. crassus (Naum.) Tim.; Mycteroligotriletes marmoratus Tim., Trachyoligotrnetes mimitus (Naum.) Tim., T. hyalinus (Naum.) Tim., T. incrassatus (Naum.) Tim., T. nevelensis Tim. T. arillatus Tim.

According to I. N. Solomina's data, the spore complex of the Ukian stratum — judging by the

Table 2

| No. in series | No. of sample | Stratigraphic horizon | Location | $\frac{Ar^{40}}{K^{40}}$ | Age in millions of years |
|---|---|---|---|---|---|
| 1 | 322 | Min'yar series, lower part of Minki stratum | Sim River basin, Min'yar settlement | 0,0520 | 760 |
| 2 | 158 | Ukian series | Basa River basin, Kulmas settlement | 0,0405 | 616 |
| 3 | 222 | Top part of the Ukian series | Revat River basin, Urman-Revat settlement | 0,0407 | 618 |

NOTE: Comma represents decimal point.

presence of Trachyoligotriletes hyalinus (Naum.) Tim., — is younger than the B'yankian stratum in the Min'yar series. B.V. Timofeyev and I.N. Solomina believe the spore complexes of the Min'yar and Ukian deposits to be characteristic of the Sinian formations.

Glauconite — the most widespread syngenetic mineral of the Inzer, Min'yar, and Ukian deposits of the Karatau series — is usually found in the form of large oval grains of aggregate structure in the terrigeneous, and often in the carbonate deposits. The size of its grains in terrgienous rocks is ordinarily several times that of the quartz fragments. These data, as well as the mode of glauconite occurrence in the section, cause us to reject the theory about possible widespread distribution of redeposited glauconite in these sediments.

The results of absolute age determination by the argon method on the basis of glauconites are incorporated in Table 2. The determination was made by N.I. Polevaya and G.A. Kazakov [18].

The aforementioned data make it impossible to assign the Min'yar series, and consequently, also the subjacent deposits of the Karatau series, to the Cambrian and Ordovician.

The views concerning the Devonian and Silurian age of the Ukian deposits are totally groundless. The transgressive overlap of the Ashinian deposits on the rocks of the Ukian series, and data obtained by the argon method, attest to the much older origin of the Ukian formations.

The available factual material allows us, in concurrence with the views held by M.I. Garanya, N.S. Shatskiy and B.S. Sokolov, to consider the rocks of the Karatau series as belonging to the Late Precambrian.

The absolute age of the glauconite from the Inzer deposits, according to data resulting from several determinations, amounts to about 900 million years. Thus, it ispossible to assume that the bottom beds of the Karatau series are not younger than 1 to 1.1 billion years, while the duration of Sinian sedimentation in the Urals should be estimated as not less than 400-500 million years. These, to a certain extent, unexpected results preclude the possibility of regarding the Sinian deposits as being formed within the limits of a single, independent period of the Paleozoic. In duration, the Sinian was five to six times longer than the longest Paleozoic period, the Cambrian, and can be compared only with the entire Paleozoic group.

These data and other arguments advanced in the studies of N.S. Shatskiy [23], B.M. Keller [9], Lee-Sy-Huang [10] and other authors, make it possible to consider the Sinian as corresponding to an independent group or even larger unit of the Precambrian.

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All-Union Scientific-Research Geologic Institute (VSEGEI) of the Ministry of Geology and Conservation of Mineral Resources of U.S.S.R., Leningrad

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# OUTLINE OF THE STRATIGRAPHY AND TECTONICS OF THE TAS-KHAYAKHTAKH RANGE[1]

by
N. A. Bogdanov

## INTRODUCTION

The Tas-Khayakhtakh Range extends for more than 300 km on a line from the upper reaches of the Indigirka River to the valley of the Selennyakh River, covering a 50-80 km wide belt, and forming the main divide between the basis of the Yana and Indigirka Rivers. Paleozoic formations are well developed within its confines. A study of these deposits was initially made in 1933 by V.A. Fedortsev [14], and in 1935-1939 by A.P. Atlasov [1], K.K. Demokidov [6], V.I. Fagutov and V.K. Lezhoyev. As a result of these surveys, Upper-Cambrian, Ordovician, Silurian, Devonian, and Lower Carboniferous deposits were identified, as well as those of the Permian-Triassic and Jurassic. In 1954-1958, geologists of the Yana Regional Geologic Administration, L.K. Dubovikov, Yu.T. Krezhevskikh, R.N. Titov, and others made geologic surveys of the Tas-Khayakhtakh Range. The results of this work were correlated by L.K. Dubovikov and V.K. Lezhoyev [7], as well as by A.A. Nikolayev [11], I. Ya. Nekrasov and V.I. D'yachenko [10], and A.V. Zimkin [8]. Nonetheless, a number of questions concerning Paleozoic stratigraphy remained unresolved and required additional study. Nor was a detailed description of the tectonic structure of the area available.

In recent years the author of this article has carried out geologic investigations in the southern and central parts of the Range, including the valleys of the Umba, Uchugey-Yuryakh, Biyergichek, Kuranakh-Yuryakh, Dogdo, on the upper reaches of the Solonya River, and other areas. These operations enabled him to prepare a more differentiated, stratigraphic chart of the region's Lower-Paleozoic formations, and to describe in greater detail the peculiarities of the tectonic structure of Tas-Khayakhtakh Range.

Our data on the stratigraphy of Upper Ordovician and Lower Silurian formations were recently published, in part [2].

In this paper we shall deal with the stratigraphy of the entire Paleozoic complex.

During field survey, a palentological collection was assembled. The specimens were identified by A.M. Obut, graptolites; Yu.I. Tesakov and V.N. Dubatolov, tabulate corals; V.A. Vostokova, gastropods, Z.G. Balashov, nautiloids; N.A. Flerova, stromatopores; R.Ye. Alekseyeva, Devonian brachiopods. The author wishes to express his profound gratitude to them for this work.

Two large tectonic structures in the Paleozoic formations can be identified the Tas-Khayakhtakh Range: the Tas-Khayakhtakh marginal uplift of the Kolyma central massif [12] and the Chibagalakh anticlinorium (Figure 1). They differ in composition and in thickness of component formations and in the pattern and intensity of tectonic dislocations.

## Stratigraphy

Paleozoic deposits make up the greater part of the Tas-Khayakhtakh Range. Distinguishable among them are the Ordovician, Silurian, Devonian, and Lower Carboniferous formations interrelated by gradual transitions without any traces of discontinuities or breaks in sedimentation. Resting upon them with sharp angular unconformity are the effusive-sedimentary formations of the Upper Paleozoic and Mesozoic.

Ordovician. Ordovician rocks are abun dant in the area discussed. Within the confines of the Tas-Khayakhtakh marginal uplift they are represented by the thick strata of carbonate formations, which includes the Uchugeyan, Usunian, Tagan'yinian, and Kharkindzhinian formations. The first belongs to the Lower, the Usunian and Taganinian — the Middle, and the Kharkindzhinian to the Middle and Upper Ordovician.

[1]Ocherk stratigrafii i tektoniki Khrebta Tas-Khayakhtakh. pp. 61 - 76.

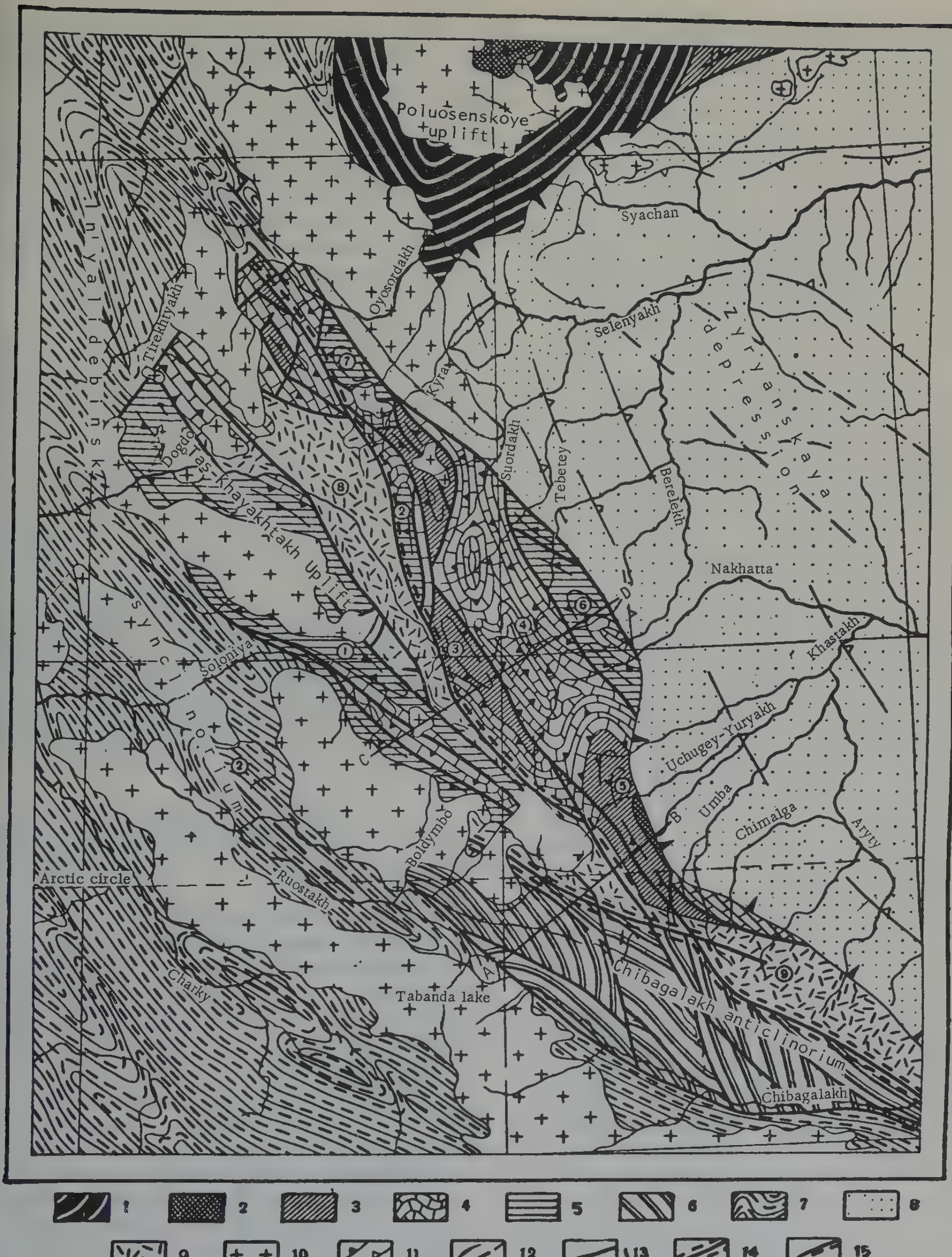


FIGURE 1. Geologic-structural map of the Tas-Khayakhtakh range. Compiled by N.A. Bogdanov using materials of Yu.A. Grebennikov, L.K. Dubovnikov, Yu.T. Krezhevskikh, V.K. Lezhoyev, R.N. Titov, and I.P. Shlykov.

A - Marginal uplifts of the Kolyman central massif: 1 - Precambrian, 2 - Lower Ordovician, 3 - Middle and Upper Ordovician, 4 - Silurian, 5 - Devonian and Lower Carboniferous; B: 6 - Lower and Middle Paleozoic of the Chibagalakh anticlinorium; C: 7 - Middle and Upper Triassic and Jurassic of the In'yali-Debinsk synclinorium; 8 - Mesozoic-Cenozoic deposits of the Zyryanskaya depression, 9 - Upper Paleozoic and Mesozoic of the superimposed basins of the marginal uplifts, 10 - Mesozoic granitoids, 11 - structural lines, 12 - axes of anticlinal and synclinal structures, 13 - faults, 14 - Chimalgino-Chibagalakh fault zone, 15 - Datinskaya fault zone. Figures on the map indicate the inner structures of the Tas-Khayakhtakh marginal uplift: 1 - Soloniya anticline, 2 - Vertinskaya syncline, 3 - Yrgandzh anticline, 4 - Kuranakh syncline, 5 - Uchugey anticline, 6 - Berelekh syncline, 7 - Oysordakh anticline, 8 - Dogo graben, 9 - Umba graben-syncline.

Rocks of the Uchugeyian formation are exposed in the valleys of the Uchugey-Yuryakh, Usuna, and Tagan'ya Rivers. They are represented by strata of black clay shales and calcareous shales, alternating with gray clayey and arenaceous limestones. The observable thickness of the formation is 1200 m. In the top part of the section gastropods were collected from the limestones which, in the opinion of V.A. Vostokova appear to be Lower Ordovician. Considering the fact that everywhere the rocks of this formation are conformably overlain by Llanvirnian rocks, we shall tentatively assign them to the Lower Ordovician.

The deposits of the Usunian formation were studied in the valleys of Usun, Uchugey-Yuryakh, and Yrgandzha. Lithologically they differ sharply from the subjacent formations and are represented by greenish-yellow calcareous-marly and marlaceous slates alternating in the upper part of the section with layers and lenses of light-grey medium-laminated limestones. In the Uchugey-Yuryakh and Tagan'ya valleys the formation is about 600 m thick. Further north, in the basin of Yrgandzha River, its apparent thickness increases sharply, attaining 1000-1200 m. The age problem of the Usunian formations deserves special attention, since until recently they were considered as belonging to the Upper Cambrian. This view was based on isolated finds of brachiopods in the Yrgandzha River valley (7, 14) some of which, in the opinion of O.N. Andreyeva (oral statement), were erroneously identified as Upper Cambrian Billinasella sp. In 1958 L.K. Dubovikov and in 1959 I myself succeeded in collecting from the same rocks in this formation an assemblage of the trilobites, Asphidae, the brachiopods, Strophomena sp., and the nautiloids, Tofangoceras sp., typical of the Middle Ordovician (Llanvirnian stage). Moreover, in sections along the Uchugey-Yuryakh and Tagan'ya Rivers, the gastropods, Maclurites sp., were found in the deposits of the Usunian formation. This also implies that the surrounding rocks are of Middle Ordovician age. All these findings justify the assertion that there are no outcrops of Upper Cambrian rocks within the limits of the Tas-Khayakhtakh uplift.

The formations of the Usunian formation in the Uchugey-Yuryakh, Oyugordakh, and Yrgandzha river valleys gradually merge with the overlying rocks of the Taganian formation. They are represented by grey massive and average stratified limestones penetrated by calcite stringers. Higher in the section, the massive limestones give way to thinly laminated rocks containing rare intercalations of black clay shales and clay limestones. The formation attains a thickness of 1600 m. A collection was made from the Taganian limestones of the brachiopods, Strophomena sp., Rafinesquina sp., Ortidae; the trilobites, Asaphidae; the gastropods, Lesueurilla sp., Pararaphistoma sp., Maclurites sp.; the nautiloids, Sactorthoceras sp., and Geisonoceras sp., which are characteristic of the Middle Ordovician. On the basis of this collection it is possible to suppose that, the Tanganian formation corresponds in age to the lower and middle parts of the Middle Ordovician Llandeylo stage. The fact that the Tanganian formation is related to the underlying Usunian formation by gradual transition (an alternation of layers belonging to both formations is observable in the transition zone), points even more convincingly to the Ordovician age of the latter.

Kharkindzhinian formation deposits cap the Ordovician section in the Tas-Khayakhtakh uplift and outcrop in the valleys of the Uchugey-Yuryakh, Boryllakha, and Artykh-Yuryakh Rivers. We have described these formations [2]. At the base of the formation one observes black calcareous-argillaceous and argillaceous slates alternating with thin layers of grey platy limestones. The over-all thickness of the Kharkindzinian formation is 180-200 m. The slates contained the graptolites, Climacograptus bicornis (Hall), Dicellograptus divaricatus Hall, Diplograptus multidens Elles and Wood, Pseudoclimacograptus aff. scharenbergi (Lapw.), Orthograptus sp., Dicarnograptus sp., Dicellograptus sp., Dictyonema sp., and other species whose ages date this formation as of Upper Llandeylo-Ashgill age.

The total observable thickness of the Ordovician within the limits of Tas-Khayakhtakh uplift is about 3900-4100 m.

The Ordovician deposits of the Chibagalakh anticlinorium differ radically lithologically from the coetaneous formations of Tas-Khayakhtakh uplift. They are intensively dislocated and metamorphozed and belong to the Kuntuchnyan formation.[2] The rocks of this formation are best exposed along the Umba and Kuntuchnya Rivers. Here, the lower half of the section is made up of green muscovite-chlorite and chlorite-quartz schists alternating with interbedded schistose quartz porphyrites and their tuffs (200 m thick), and marmorized limestones. The upper section of the formation is composed of quartz-muscovite, quartz-feldspathic, and quartz-chlorite schists. The total apparent thickness of the Kuntuchnyan formation is approximately 1600 m. Paleontologically, these deposits are poorly characterized. The lower part of the formation contains the stromatopores, Beatricea sp., known to occur in the formations of Middle and Upper Ordovician in North America. Considering the

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[2]L.K. Dubovnikov and V.K. Lezhoyev [7] assigned the Kuntuchnyan formations to the Proterozoic.

the fact that the Kuntuchnyan rocks concordantly underlie the coral limestones of the Lower Silurian, we assign them to the Ordovician.

Silurian. The Silurian deposits were studied over the entire area of the region under review. In the Tas-Khayakhtakh uplift they are represented mainly by dolomites and dolomitic limestones. Identifiable in this stage are the Omulevian (Lower Silurian), Umbian (Lower Ludlow), and Datnian (Upper Ludlow - Lower Devonian) formations.

The rocks of the Omulevian formation are exposed in the valleys of the Uchugey-Yuryakh, Boryllakha, and Artykh-Yuryakh Rivers and lie conformably everywhere on the Kharkindzhinian formations [2]. At the base of the Omulevian formation one finds a bed of black clay shales containing thin bands of limestones. Higher in the section they are replaced by limestones containing grey, medium-platy, which at the very top alternate with clay shales. The formation is 220-250 m thick. The slates of the Omulevian formation have yielded the graptolites, Monograptus sp., M. lobiferus (McCoy). M. inornatus (Harkness), M. ex gr. flemingi (Salter), Pseudoclimacograptus nughesi (Nicholson), Petalograptus ex gr. palmeus (Barr.), Pernorograptus revolutus (Kurck.), Rastrites longispinus Perner, etc., which put the formation in the Llandoverian - Venlockian age group.

The overlying Umbian series grades into the Omulevian formation. It outcrops along the right tributaries of the Dogdo River, Datna I and Dadyn'ya streams, as well as in the upper reaches of the Umba, Boryllakha, and Solonya. The lower part of the Umbian section consists of dark-grey, massive dolomitic limestones showing thin bands. Higher up they give way to white and light-grey dolomites alternating with bands of yellowish-green and red marl slates and pink dolomites having a thickness of 50-100 meters. The top portion of the section consists of grey, variously laminated dolomitic limestones. In the western and northern parts of the uplift the top sections of Umbian formation contains a 70-100-m bed of coarse- and fine-pebble, brecciated conglomerates. The pebbles and brecciated debris in them originate from the limestones and dolomites in the bottom of the formation. The layer of brecciated conglomerates gradually pinches out in the southeasterly direction. The over-all thickness of the rocks in this formation is 1700-1800 m. The following tabulate corals species were found in the Umbian deposits: Favosites cf. niagarensis Hall, Fav. sp., as well as stromatopores and gastropods. These fossils date this formation as Lower Ludlow.

Exposures of the Datnian formation deposits occur in the valleys of the Kuranakh-Yuryakh, and Nakhatta Rivers, as well as along the tributaries of the Dogdo — Datna I, Dadynya, and Khobochalo streams. Everywhere they rest conformably on Umbian rocks. In the Kuranakh-Yuryakh and Nakhatta valleys the base of formation consists of dark-grey argillaceous limestones which, further up the section, change to laminated dolomitic limestones. Layers of organic-clastic detritus are found interbedded in them. The top section of the formation is composed of massive grey limestones interbedded with layers of coral limestones, which usually do not exceed 25-40 m in thickness. The total thickness of the deposits of this formation in these sections amounts to 1000-1100 m. In the western part of the uplift the Datnian sequence exhibits a facies change. Here, the base of the formation consists of grey coral limestones which alternate with layers of medium-laminated dolomitic limestones in the upper parts of the section. The total thickness of the formation decreases to 550-650 m along the course of the Datna I.

The age of the Datnian formations is, in the main, determined on the basis of corals, which, in addition to the Upper Ludlow species, includes Favosites forbesi M. Edw. and Haime, Fav. forbesi M. Edw. and Haime var. mammilatus Tchern., Fav. aff. coreaniformis Sok. Squameofavosites sp., Dictyofavosites aff. tchernajaensis Dubat. One also finds the Lower Devonian specimens: Striatopora tschichatschewi Peetz., Parastriatopora ržonisnckajae Dubat. and Pseudomicroplasma sp. This is the basis for beleiving that the Datnian series is of Upper Ludlow - Lower Devonian age.

The over-all thickness of the Silurian deposits in the eastern section of the uplift reaches 3000-3100 m and decreases to 2300-2500 m in the western part.

In the Chibagalakh geanticline the Silurian sequence is changed. In the upper reaches of the Umba and Tukchana Rivers beds of metamorphosed limestones and slates of the Tukchanian formation lie conformably on the Kutuchnyan metamorphic schists. The bottom of the former is predominately quartz sandstones and marmorized limestones interstratified with quartz-sericitic schists. The upper part of the section consists mainly of marmorized limestones containing thin bands and lenses of phyllite and quartz-sericitic schists. The Tukchanian formation are about 2000 meters thick. The following fossils were collected from the base of the formation in the marmorized limestones: Favosites sp., Palaeofavosites longispinus Tchern., Mesofavosites sp., Syringopora sp., Catenipora aff. parallelus Schmit., C. aff. gothlandicus Yabe, C. vulgaris Tchern., the most of which are typical of the Llandoverian stage of the Lower Silurian. Discovered in the middle part of the section were the tabulate corals, Favosites forbesi, M. Edw. and Haime

var. coreanicus (Ozaki) and Fav. sp. which characterize the age of the overlying formations as belonging to the Wenlock-Ludlow stages. On the basis of the foregoing data we consider the age of the Tukchanian formation to be Silurian.

Devonian. All three Devonian formations, interrelated by gradational transition, are identifiable within the limits of the Tas-Khayakhtakh uplift. In recent years they were described by L.K. Dubovikov [7], and studies in detail by R. Ye. Alekseyeva and V.N. Dubatolov, whose materials, together with our own observations, are utilized in this article.

Lower Devonian deposits outcrop along the banks of the Dadyn'ya, Khobochalo, and Kuranakh-Yuryakh Rivers. In the latter's valley they occur as dolomite beds of average thickness and dolomitic limestones whose strata contain individual beds of coral limestones attaining 20 to 25 m in thickness. The Lower Devonian deposits here are about 600-650 m thick. Further west the sequence of the coetaneous deposits is somewhat modified. Along the tributaries of the Dogbo River and in the valleys of the Khobochalo and Dadynya streams the base of the section is made up of grey, banaded, coral limestones. Higher up, they give way to grey and dark-grey dolomites, which contain the tabulate corals: Syringopora abdita vern., S. aff. borealis Tchern., and the brachiopods, Delthyris tenusinuosus Khod., D. ex. gr. tiro Barr., etc. The over-all thickness of this section is about 350-400 m.

Eifelian deposits are exposed in the Dogdo River basin. They are represented by black calcareous clay shales and slates alternating with thin bands of dark-grey shaly limestones containing the brachiopods, Gypidula aff. ivdelensis Khod., Carinatina raris Ržon., Spinatrypa ex gr. aspera Schloth., Atrypa ex gr. reticularis L., Eospirifer irbitensis Tchern.; the tabulate corals; Pachyfavosites sp., Alveolitella sp., Favosites aff. goldfussi Orb., Fav. robustus Lec., Syringopora cf. crispa Schluter, etc.; as well as specimens of trilobites, crinoids, and tetracorals, characteristic of the Eifelian stage of the Middle Devonian. These deposits were found to vary in thickness from 250 to 500-600 m.

Givetian deposits were studied along the Khobochalo, Sebechan, and Dadyn'ya streams. They are represented by grey and light-grey dolomitic limestones and interbedded dolomites containing the tabulate corals; Scoliopora ex gr. denticulata (M. Edw. and Haime), Thamnopora ex gr. polyforata (Schlothem), Alveolitella sp., Cladopora sp., Syringoporella sp., Clathrodictyon sp., and the brachiopods; Stringocephalus burtini Defr. In the top of the sequence the dolomites alternate with individual lenses and non-uniformly striking bands of red and greenish-yellow marls, calcareous-marly slates and anhydrites, varying in thickness from 10-15 to 200-250 m (the right-headwaters of the Tuostakh River, [7]). The total thickness of the Givetian stage deposits is about 450-500 m.

Upper-Devonian deposits are represented by grey and light-grey, medium-laminated dolomitic limestones. They were encountered in the valleys of the Emtachan and Dadyn'ya Rivers. However, these sections fail to display the youngest formations of the Upper Devonian. In the dolomites of the Emtachan valley, L.K. Dubovikov [7] succeeded in collecting specimens of Nalivkinella sp., Thamnopora nalivkina Tchern., Th. reticulata Blainv., Th. sp., Alveolitella (?) aff. karmakensis Tchern., which give evidence of the Upper Devonian age of these formations. The observed thickness of the Upper Devonian deposits attains 100-110 m. The over-all apparent thickness of the Devonian in the Tas-Khayakhtakh uplift is about 1500-1800 m.

The Biyergichekian formation is a formation of the Lower and Middle Paleozoic in the general area of the Chibagalakh anticlinorium.[3] The Biyergichekian rocks are less metamorphosed than are the Tukchanian and Kuntuchnyan formations, and are in contact with the latter along the faults. The Biyergichekian rocks are best exposed in the valley of the Biyergichek River and along its tributaries. The basal strata of the formation here consist of reddish-brown quartz sandstones with thin bands of phyllite slates. The middle of the formation consists of quartz-like sandstones and phyllite slates, and the upper part is entirely composed of black and dark-grey phyllite slates. The total observed thickness of these deposits is approximately 2000 m. The age of the Biyergichekian formation has not been definitely established.

Carboniferous. Carboniferous deposits were investigated only in the central portion of the Tas-Khayakhtakh uplift along the tributaries of the Dogdo River in the valleys of the Uklin and Dzhabul'denga. Their relation to the subjacent rocks, so far, have not been determined. The formations of this age are represented by grey, laminated limestones interstratified with black argillaceous and calcareous-argillaceous shales. In the limestones L.K. Dubovikov and R.Ye. Alekseyeva found the brachiopods, Spirifer cf.

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[3]Earlier L.K. Dubovikov and V.K. Lezhoyev [7] assigned this formation to the Sinian. According to the new data produced by V.K. Lezhoyev and G.N. Loginova (verbal report) the Biyergichekian formation should be considered as a stratigraphic equivalent of the Kuntuchnyan formation and attributed to the Ordovician.

ornacensis Kon., Linoproductus cf. panderi Auerb., Stereophrentis ex. gr. disjuncta (Carr), and other fossils of the Tournaisian and the lower part of the Visean stages. The apparent thickness of the Carboniferous deposits is 350-400 m.

In summing up the above description of the Paleozoic sections in the Tas-Khayakhtakh Range, it seems important to dwell on some of their special features. Within the limits of the Tas-Khayakhtakh marginal uplift, just as in the uplift of the Cherskiy Range [4], the Paleozoic formations are represented chiefly by the rock of the carbonate series. The abruptly increasing thickness of the Upper Silurian and Devonian formations in the eastern part of the uplift (Kuranakh-Yuryakh and Berelekh River basins - Figure 2) is attributable to the fact that it was here that the central and most downwarped part of the large Paleozoic depression extending from the Omulyevskiye Mountains in the Southwestern part of the Kolyma central massif [3] and stretching out in a southwesterly direction, was located. A more complex Paleozoic structure exists within the confines of the Chibagalakh geanticline. The Ordovician rocks are represented here by terrigenous formations and marmorized limestones containing rare bands of schistoze acid effusives, whereas in Tas-Khayakhtakh uplift, as mentioned earlier, limestones and marl slates comprise the Ordovician. The facies of the deposits of the Lower Silurian of these two structural zones are also different. If, in the marginal uplift they consist of a thin band of graptolite schists, in the Chibaglakh anticlinorium the Lower Silurian is represented by a thick stratum of coral limestones. It is to be regretted that it is difficult, at the present time, to compare the Biyergichekian formation with any known formation, since it has not yet been paleontologically defined. On the whole, the over-all composition of the Paleozoic rocks in the Chibaglakh anticlinorium suggests that the sedimentation conditions here were different from those in the adjacent Paleozoic trough in the southeastern part of the Kolyma central massif.

Upper Paleozoic and Mesozoic. The Upper Paleozoic and Mesozoic formation occur in the Dogdo graben and in the Umba graben-syncline. They are thoroughly described by L.K. Dubovikov and V.K. Lezhoyev [7], as well as by A.V. Zimkin [8], on the basis of materials collected by V.P. Fagutov, D.P. Vas'kovskiy, V.K. Lezhoyev, and L.K. Dubovikov. We shall refer to them very briefly in this paper.

In the Khobochalo stream basin in the northwestern part of the Dogdo graben the Silurian and Devonian rocks are transgressively and unconformably overlain by Lower Permian conglomerates and arenaceous limestones, whose observed thickness is 70-80 m. Further south in the valley of the Krest-Yuryakh River, also lying unconformably on Middle Paleozoic limestones, there is a 250-300 m formation of shales, tuffaceous sandstones, diabase porphyrites and their tuffs containing Middle Triassic ammonites. The relationship between the Permian and Triassic deposits in the Tas-Khayakhtakh Range was not determined. The described Paleozoic rocks, as well as the Permian and Middle Triassic formations, are unconformably overlain by Upper Jurassic basic and acid effusives and their tuffs, containing shale and sandstone layers. It is mainly these formations which fill the Dogdo graben and the other graben-like structures in the Tas-Khayakhtakh Range. In the Kyra River valley, in the northern part of the Dogdo graben, in the formation of shales in the lower part of the section, one observes lenses of brown coal about 0.6 m thick. The total thickness of the Upper Jurassic deposits in the Dogdo graben is 2000 m. The younger rocks covering the Paleozoic and Mesozoic deposits are the Tertiary and Quaternary alluvial and deluvial formations which are widespread in the Zyryanskaya depression which bounds the Tas-Khayakhtakh uplift on the northeast.

## Tectonics

As stated above, the principal tectonic elements of the Paleozoic structure in the Tas-Khayakhtakh Range are the Tas-Khayakhtakh marginal uplift of the Kolyma central massif, and the Chibagalakh anticlinorium (see Figure 1), which differ in the composition and thickness of the component rocks, as well as in the intensity and type of tectonic dislocations.

The Tas-Khayakhtakh uplift is the western extension of the Kolyma central massif which extends from the Indigirka River valley in the northwest, then in a near-meridional direction to the valley of the Selennyakh River. Its total length is 300 km with a maximum width ranging from 50 to 70 km. On the west, the Tas-Khayakhtakh uplift is bounded by the Chimalgino-Chibagalakh fault zone which separates it from Chibagalakh anticlinorium and the In'yali-Debinsk synclinorium. In the east, the uplift abuts on Zyryanskaya depression which is filled with Mesozoic and Cenozoic formations. The Lower and Middle Paleozoic rocks which comprise the uplift are contorted into large folds and are cut by numerous strike and diagonal faults which are responsible for its complex block-fold structure.

The following tectonic structures from east to west, trend in a northwesterly direction, can be identified within the limits of the marginal uplift: (Figure 1): Berelekh brachyanticline [6], Kuranakh syncline [4], Uchugey antiline [5], Yrgandzhi anticline [3], Oysordakh anticline [7], Vertinskaya syncline [2], and the Solon'ya anticline [1]. The two latter structures are separated

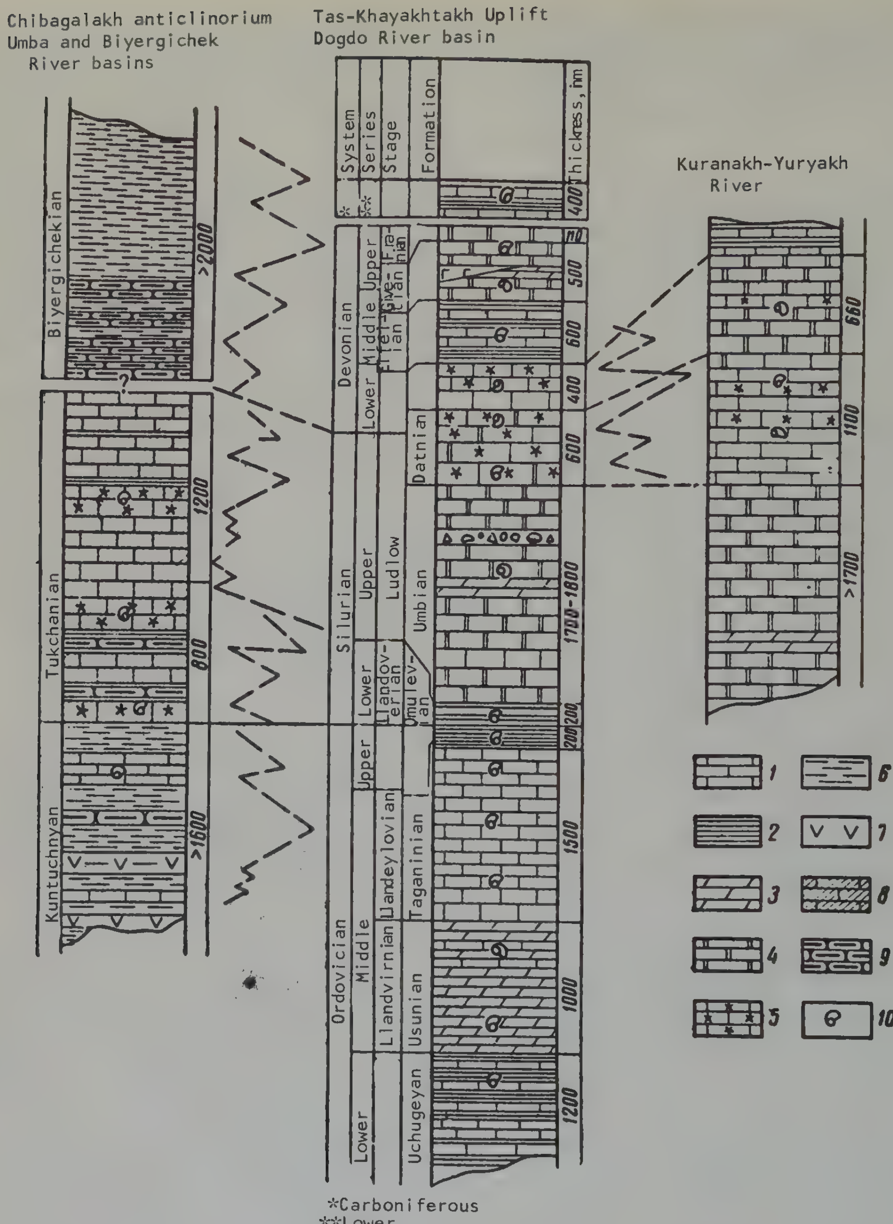


FIGURE 2. Comparison of the stratigraphic columns of the Paleozoic in the Tas-Kyakhtakh Range.

1 - limestones, 2 - shales, 3 - marls, 4 - dolomites, 5 - coral limestones, 6 - metamorphic schists, 7 - schistose effuses, 8 - marmorized limestones, 9 - quartzites, 10 - fossil locations.

by the Dogdo graben [8] extending to the Umba graben-syncline. Both are filled with Upper Paleozoic and Mesozoic effusive-sedimentary formations.

The Berelekh brachyanticline extends from the Suordakh River valley to the Middle course of the Nakhatta River for a distance of 50 km, and has a width of 25 to 30 km. This structure can be described as dome-shaped, and it is somewhat elongated in the meridional direction. The center of the brachyanticline consists of rocks of the Datnian formation (Figure 4). They form a gentle arch with an 8-15° pitch. Toward the limbs, the dip becomes steeper and reaches an angle of 25-30°. The eastern limb of the brachyanticline is truncated by a fault which separates it from the Zyryanskaya depression. In the fault zone the rocks are crumpled into minor folds tilted toward the east. The width of the folds in the fault zone does not exceed 0. 5-07 km. The western limb of the Berelekh brachyanticline is also complicated by a longitudinal fault separating it from the Kuranakh syncline.

The Kuranakh syncline is traceable from the middle course of the Nakhatta River to the upper Kyra River, a distance of more than 100 km. The syncline is 30 - 40 km wide. The eastern limb of the structure is everywhere truncated by faults separating it from the Zyryanskaya depression and the Berelekh brachyanticline. The Upper Silurian rocks comprising the western limb of the syncline dip in a northeasterly direction at an angle of 25-30° as a monocline which gradually flattens out toward the east. The syncline core is composed of nearly horizontal Datnian formations. Only gentle bending of the beds is observed in this part of the structure.

In the Nakhatta River valley, following the trend of the Kuranakh syncline, and south of its centroclinal closure, lies the Uchugey anticline.

The Uchugey anticline has an almost meridional strike and is traceable from the Nakhatta River valley to the Umba River. It is 70 km long, and has a width of about 25 to 30 km. Here, we were able to investigate only the western part and the northern periclinal closure of the anticline. The eastern limb and the southern periclinal closure of the fold plunge step-by-step along the longitudinal faults under the formations of Zyryanskaya depression. The Ordovician rocks which make up the western portion of the core and the anticline limb form a monocline where the dip of the beds increases from east to west from 25-30° to 45-50°. In its western marginal section the monocline is complicated by faults and upthrusts with negligible throw. In this faulted zone, laminated limestones and shales are contorted into small flexures, while the more massive rocks are usually slightly recrystallized and crushed. The pattern of the northern periclinal closure of the Uchugey anticline is more complex. The component Taganian formation limestones are contorted into a number of minor folds whose bends have a steep northward pitch. The dips of these folds vary from 25° to 40°.

The Yrgandzhi anticline is situated northwest of the Uchugey anticline, forming a step-like pattern with the latter. It is bounded on all sides by faults and extends in an almost meridional direction from the Sebechan River to the Boryllakh River for a distance of 35-40 km, and is 8-10 km wide. The bend of the structure exhibits a northward rise, and here in the Yrgandzha and Inarodzha River valleys the Ordovician rocks of the Usunian and Taganinian formation in the core are exposed. They form a steep crest-like anticlinal fold, whose limbs gradually flatten out to the west and east (see Figure 3). The dip of their beds changes from 50°-60° to 25°-30°. Further south, on the upper reaches of the Artykh-Yuryak River the anticline core has a less complex structure. Here, the Ordovician formations form a gentle arch with the strata dipping at an angle of 25°-30°. The limbs of the Yrgandzha anticline are composed of Silurian rocks and everywhere display a simple structure. The component rocks plunge at an angle of 10°-20° and are crumpled into small complex folds only as they reach the edges of the faults. The fault which bounds the Yrgandzhi anticline on the west is the border between it and the Mesozoic Dogdo graben and the Vertinskaya syncline.

The Vertinskaya syncline is composed of Upper Silurian and Devonian rocks. It is 10-12 km wide and extends for 40 km from the upper Kyra river on the north to the Inarodzha River on the south. On all sides it is surrounded by ruptured zones. On the whole, the Vertinskaya syncline has an oval shape. Its limbs are complicated by minor and larger folds. Thus, the rocks of the syncline's western limb in the valley of Datna I stream, in the ruptured zone which separates the syncline from the Dogdo graben, are contorted into small folds manifesting a dip of 70°-80°. In individual blocks and wedges it was possible to observe a westward overturning of folds in the direction of the graben. The eastern limb of the Datna syncline is much simpler in structure. The Umbian limestones, of which it is composed, form a monocline, which dips 40°-50°, complicated by a sloping box fold of secondary order. The syncline's crest rises in the northwest, and here the northern centroclinal closure of the trough is replaced by the tectonic elements of the Oysordakh anticline.

The Oysordakh anticline is located in the northeastern part of the Tas-Khayakhtakh uplift

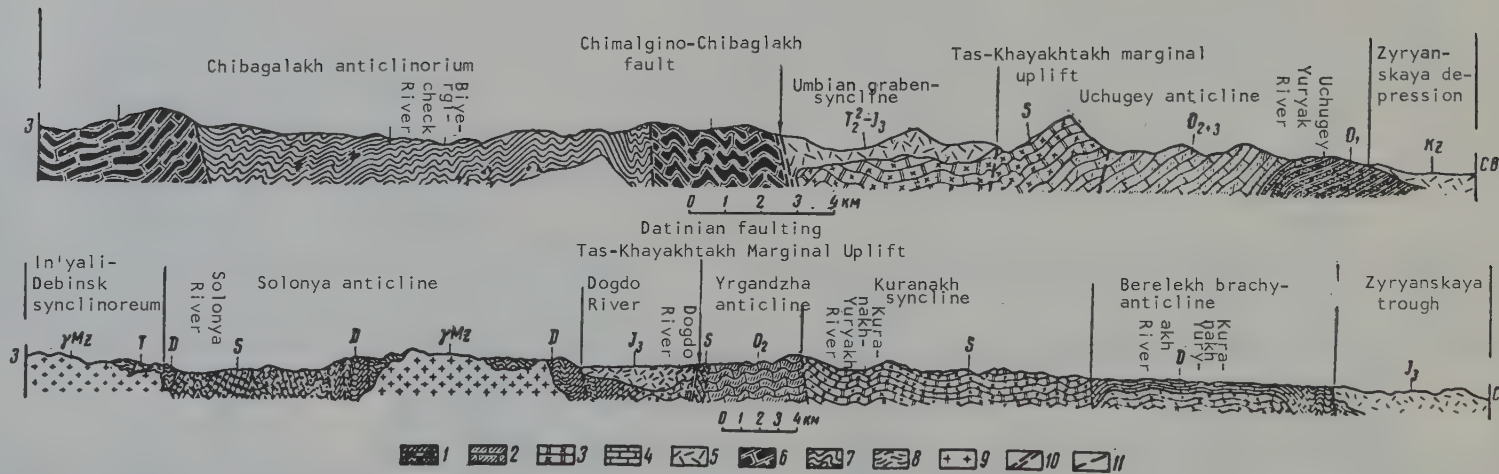


FIGURE 3. Schematic geologic sections across the Tas-Khayakhtakh Range.

Tas-Khayakhtakh marginal uplift of the Kolyma central massif: 1 - Lower Ordivician, 2 - Middle and Upper Ordovician, 3 - Silurian, 4 - Devonian, 5 - Middle Triassic and Upper Jurassic.

Chibagalakh anticlinorium; 6 - Tukchanian formation, 7 - Biyergichekian formation, 8 - Triassic of the In'yali-Debinsk synclinorium, 9 - Mesozoic granitoids, 10 - deep-seated faults, 11 - dislocated zones.

between two Mesozoic granite batoliths — the Khadaryninskiy [10] in the east, and the Tirekhtyakhinskiy, in the west — and was described by P. N. Titov. The inner anticline structure is complicated by two discontinuous dislocations: the northwestern and the southeastern. The first is traceable along the entire Tas-Khayakhtakh uplift and separates it from the Zyryanskaya depression. The second is the western continuation of the faults which fringe the Polousenskoye uplift on the south. They cut the Oysordakh anticline into a number of separate tectonic blocks trending to the northwest. The anticline's core is composed of Ordovician and Silurian rocks, with Devonian formations on its limbs. The limbs have a 60° to 75° dip. In the zones adjacent to the faults, the Lower and Middle Paleozoic deposits are recrystallized and intruded by a large number of diabasic dikes.

The most complex structure occurs in the western part of the Tas-Khayakhtakh uplift where the Solon'ya anticline is situated. On the west it is in contact with the In'yali-Debinsk aynclinorium along a fault, and is adjacent to the Dogdo graben on the east. It extends southeast - northwest for almost 80 km, maintaining a width varying from 10 to 12 km. The Solonya anticline is a narrow linear fold, its limbs and the northwestern periclinal closure complicated by faulting. Umbian rocks belonging to the Lower Ludlow form the core of the anticline. They are folded and crumpled into steep (dip of the beds, about 70°) symmetrical folds trending northwest, are complicated by faults and upthrows with a displacement of several hundred meters. The western limb of the Solonya anticline is composed of Upper Ludlow and Lower Devonian rocks and is complicated by narrow, linear, second order faults, showing bed dips attaining 75° - 80°. The Devonian limestones which make up the eastern limb of the structure form a monoclinal flexure, ruptured by numerous longitudinal faults. Only in the ruptured zone is the monocline complicated by minor folding.

The Umbian graben-syncline and the Dogdo graben are located in the central and southern parts of Tas-Khayakhtakh marginal uplift. They are the northernmost structures in the narrow belt of Mesozoic troughs traceable from Lake Darpir in the southeast, to the basin of the Kyra River on the northwest. The Mesozoic troughs extend along a system of major faults which delineate the central massif and are superimposed on the Paleozoic folds of the marginal uplifts (see Figure 3).

The Umbian graben-syncline is confined to the Chimalgino-Chibagalakh fault zone and strikes in almost latitudinal direction for some 35 km. Its maximum width is 5-8 km. The inner part of this structure is complicated. In cross-section, it is sharply asymmetrical because of the general dip and occasional southwesterly overturn of the layers in the direction of the Chimalgino-Chibagalakh fault zone. The Umbian graben-syncline is not structurally uniform. In its central and northeastern parts, the Upper Jurassic effusives manifest a gentle 5°-7° dip, like a monocline sloping in a south-southwesterly direction. The Middle Triassic shales and sandstones and Upper Jurassic effusives, which comprise the western section of the graben-syncline, abut on the fault zone and are crumpled into a series of small folds, sometimes tilted southward with a dip varying from 50-70° to 15-25°. At the contact with the faults the rocks are recrystallized and schistose and form dislocation breccia and slicken sides. Along a line from the east to the northwest, the graben-syncline narrows abruptly, and here it is connected with the Dogdo graben by a narrow (2-3 km in width) graben extending along the Datnian fault. The graben is composed of Middle Triassic and Upper Jurassic rocks forming an asymmetrical fold, the most downwarped part of which is coordinated with the Datnian fault. The Mesozoic formations are intensively cataclasticized in the fault zone.

As described earlier, the Dogdo graben is situated further to the north in the central part of the Tas-Khayakhtakh uplift. It extends in northwesterly direction from the upper reaches of the Goredomchan-Yuryak River to the latitudinal bend of the Dogdo River. Its width attains 30-35 km and its length totals 100 km. Permian rocks comprise the western limb, while the central and eastern sections are composed of Upper Jurassic deposits unconformably superposed on Middle Paleozoic rocks. On the northeast, the Dogdo graben is bounded by the Datnian fault. On the opposite, southwestern side, the graben is also truncated by faults, although of lesser importance. Asymmetrical structure is, on the whole, characteristic of this graben, just as it is for the Umbian graben-syncline. In its 20-25 km wide western part, the Permian and Upper Jurassic rocks have a relatively gentle, 3°-6° eastward dip. They form a gentle monocline complicated by small gentle quaquaversal folds. The more folded, 5-8-km wide eastern part of the Dogdo graben exhibits more complex structure. The Upper Jurassic effusives are crumpled here into small folds, whose limbs dip at increasing angles in an easterly direction, from 10-15 to 25-30°, as the folds approach the Datnian fault.

Thus, the Tas-Khayakhtakh marginal uplift constitutes a complex block-and-fold structure consisting of a number of major Paleozoic folds and superimposed Mesozoic structures of the graben and graben-syncline type.

One should dwell a little longer on some of the general features of the uplift structure (see Figure 3). Large folds with limbs extending

for 25-30 km are developed in its eastern part. In the central parts of these folds the rocks are almost horizontal, dipping at an angle of 15-30° on the limbs. The latter are usually faulted, emphasizing the block-and-fold pattern of this territory. In the western part of the Tas-Khayakhtakh uplift, this type of folding gives way to linear structures traceable for 30-40 km, over a 5-7 km wide belt. The limbs of these folds dip steeply at a 50-70° angle, and in the cores of crest-like anticlines the beds are vertical. The width of this zone of linear folding does not exceed 25-30 km.

The foregoing data indicate that the degree of dislocation affecting the Paleozoic rocks in the Tas-Khayakhtakh uplift gradually increases from east to west away from the central part of the Kolyma central massif. Permian and Mesozoic rocks are almost horizontal within the limits of the uplift and are dislocated only in the fault zones.

The Chibagalakh anticlinorium is the eastern element of the Yana-Kolyma megasyncline [13] and is located on the southwestern slope of the Tas-Khayakhtakh Range. It covers an area 35-50 km wide and 150-200 km long stretching from the Khara-Sal valley to the lower course of the Chibagalakh anticlinorium borders on the Inyali-Debinsk synclinore which is filled with Triassic, Upper, Middle, and Lower Jurassic deposits aggregating 3000-4000 m in thickness [5]. In the north and northeast, the geanticline is bounded by the Chimalgino-Chibagalakh fault zone which separates it from the Tas-Khayakhtakh uplift of the Kolyma central massif. The Chibagalakh anticlinorium is formed by intensely dislocated Paleozoic rocks and is broken up by widespread longitudinal and diagonal faulting into a number of horsts and grabens (see Figure 1), which make it difficult to differentiate its structure as a whole.

The central part of the geanticline is composed of Ordovician metamorphic rocks, with Silurian deposits on its limbs.

The metamorphic schist and marmorized limestones of the Kuntuchnyan formation which make up the Chibagalakh anticlinorium's core are contorted into complex isoclinal folds whose limb spread out for 50-100 m. The beds are tilted to the northeast at an angle of 40-60°. In that part of the core which is directly contiguous to the Chimalgino-Chibagalakh fault zone, the dip of the isoclinal folds becomes steeper, attaining an angle of 75°-80°. Here, the folds rarely exceed 25-35 m in width.

The anticlinorium's eastern limb is formed by Tukchanian limestones and is cut by diagonal faults into separate blocks plunging in a step-like pattern to the east. The rocks are folded here into recumbent folds overturned to the northeast at an angle of 50°-60°. The spread of their limbs does not exceed 50-150 m, and their axes have a steep pitch, so that in longitudinal section these folds have a box-like shape. The western limb of the Chibagalakh anticlinorium is composed of the Tukchanian and Biyergichekian formation and is separated from the core of the anticlinorium by major faults having latitudinal and northeastern strikes. There is less intense dislocation in this portion of the structure than in its core and eastern limb. The western limb is complicated by regular linear, both symmetrical and asymmetrical, folds which, as a rule, are overturned in the southeasterly direction (see Figure 3). Usually, asymmetrical folding can be observed in the zones of the minor faults which complicate the limbs of second and third order folds. On the middle course of the Khara-Sal River, the western limb of the Chibagalakh anticlinorium is in contact with the tectonic elements of the In'yali-Debinsk synclinore along the fault. The internal structure of this synclinore has been described by several authors [13, 5, 8].

As can be seen from the above brief description, the Chibagalakh anticlinorium is structurally far more complex than the Tas-Khayakhtakh marginal uplift of the Kolyma central massif. Thereis no isoclinal folding similar to that which complicates the structure of the Chibagalakh geanticline, anywhere within the limits of the marginal uplift. Moreover, there are almost no recumbent narrow folds in the marginal uplift. Common to these two major folded systems are the numerous faults responsible for their block-and-fold structural pattern.

The Chimalgino-Chibagalakh fault zone which we defined, separates, as previously mentioned, two different tectonic elements: the central massif, marginal uplift of the Tas-Khayakhtakh and the Chibagalakh geanticline, located within the confines of the geosynclinal zone. This zone extends from the middle course of the Chibagalakh River to the Boldymbinskiy batholith for 350-400 km in a northwesterly direction, and controls in the south, the narrow belt of Mesozoic effusives. Along the Chimalgino-Chibagalakh fault zone, following the contact between the Jurassic effusives and the Paleozoic rocks, there is a thick (up to 100 m thick) band of fault breccia and mylonites. The effusives are more highly crushed and altered here. The marmorized Paleozoic limestones and metamorphic schists are recrystallized and particularly intricately corrugated in the fault zone. The presence of fault breccia and mylonites in the Jurassic effusives and Paleozoic rocks indicates that that development of the Paleozoic formations was of very long duration. The Chimalgino-Chibagalakh fault zone apparently, must have

been formed in the early Paleozoic at the boundary between two large structures, and maintained its tectonic activity throughout the entire Paleozoic history of this region. This may, no doubt, explain the difference between the Paleozoic sections of the Tas-Khayakhtakh uplift and the Chibagalakh anticlinorium.

## CONCLUSIONS

We shall now deal with a few basic problems relative to the development of the tectonic structures in the investigated area.

There are no outcrops of Pre-Ordovician formations within the limits of the Tas-Khayatakh Range, and we are, therefore, unable to dwell at the present time on the older stages of the region's tectonic history. As already mentioned, the formation of a depression filled mostly with carbonate deposits occurred within the confines of Tas-Khayakhtakh uplift — as well as over the entire southwestern area of the Kolyma central massif — in the period embracing the Lower Ordovician to the Lower Carboniferous, inclusively. Another structure-facies zone was located further west from this downwarp in the region of the Chibagalakh anticlinorium and, possibly, also over the greater part of the In'yali-Debinsk synclinore. Thick terrigeneous strata containing individual beds of acidic effusives and their tuffs, are characteristic of this zone. The boundary between these two areas ran along the Chimalgino-Chibagalakh fault zone.

There was no sedimentation in the Middle and Upper Carboniferous within the limits of the presently reviewed central section of the Mesozoids in Northeast Asia. At the same time, Permian formations are found deposited with a mark angular unconformity on the older Paleozoic deposits. On the basis of this fact, it is possible to postulate that the formation of the principal Paleozoic folded structures was terminated in the Pre-Permian epoch. The amount of dislocation affecting the Paleozoic rocks in the Tas-Khayakhtakh uplift gradually increases from east to west, and formations of this age are very complexly contorted within the limits of the Chibagalakh geanticline. It appears, that in the Middle and Upper Carboniferous the tectonic movements were most intensely manifested in the eastern part of the Yana-Kolyma megasyncline, gradually decreasing in the direction of the ancient core of the Kolyma central massif.

Throughout the entire Mesozoic history — that is, during the long period of time when the recent structures of the Yana-Kolyma megasyncline were in the process of formation — the Tas-Khayakhtakh uplift must have reacted to tectonic movements by forming individual horsts and grabens and by complicating the folded structure of its western marginal section. The Datnian fractured zone, along which — like the faulted zone of Chimalgino-Chibagalakh — there occurred a discharge of effusives in the Middle Triassic and Upper Jurassic, probably must have also developed during this period. Thus, at this stage of development, the Tas-Khayakhtakh marginal uplift — as well as the entire Kolyma central massif — was a fixed elevation to the outlines of which the folded structures of the geosynclinal zone have adapted themselves in, so to speak, a streamlined pattern. The appearance of primarily block-type dislocations within the uplift in Mesozoic time is also indicated by the horizontal bedding, within its limits, of Upper Paleozoic and Mesozoic deposits. The latter are dislocated only in fault zones where the vertical movements appear to have continued into Post-Cretaceous time.

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Geological Institute of the
U.S.S.R. Academy of Sciences,
Moscow

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# HE FACIES, DYNAMIC PHASES AND FORMATIONS OF ALLUVIUM[1]

by
I. P. Kartashov

Studies of alluvial deposits are of great
actical importance for the exploration,
ospecting, and mining of placer mineral
posits, for building dams, canals, roads,
d other construction projects, and also
r many purposes in other fields of the national
onomy. The considerable successes achieved
this research during recent years do not,
wever, offset very substantial shortcomings.
e cannot, for example, fail to point out the
ct that the genetic peculiarities of alluvium,
which this article is devoted, are still very
orly studied. Yet, many of these features,
ile considerably affecting the lithology of
luvium, are also of great importance to
ratigraphic and paleogeographic develop-
ent.

The factual material upon which the posi-
ons taken in this paper were formulated is
sed on the data of numerous exploratory
d prospecting operations conducted in alluvial
ld placers in different parts of the Soviet
ion.

## Facies of Unconsolidated Deposits

Present-day genetic studies of unconsoli-
ted deposits are no longer, as a rule, con-
ed to mere classification into genetic types.
acies" has now become the most commonly
ed designation for the genetic subdivisions
the succeeding order serving as the princi-
l object of study. However, the definition
facies as a lithologically homogeneous com-
ex of deposits [9, 13] is hardly applicable to
ntinental, unconsolidated deposits distin-
iishable, as is well-known, by excessive
riations of lithologic characteristics. A
ference to S. A. Yakovlev's genetic classifi-
tion of Quaternary deposits [13] can furnish
good illustration of this fact. None of the
ntinental facies identified therein can satisfy
e requirements of lithologic uniformity on
hich S. A. Yakovlev so emphatically insists
3, pp. 41-43].

The term unconsolidated sedimentary facies properly should be applied to complexes of rocks of the same genetic type formed under identical geomorphologic conditions. The relating of unconsolidated deposits to one and the same facies must, therefore, be determined by their coincidence with the same development stages or relief forms.

An overwhelming majority of investigators consider alluvium as an independent genetic type. Since the publication of Ye. V. Shantser's study [12] on the alluvia of plains rivers, it has become common to class alluvial deposits into three genetic complexes: channel, flood-plain, and oxbow complexes. Each of these complexes fully corresponds to the above definition of unconsolidated sedimentary facies. In S. A. Yakovlev's classification [13] these complexes are, indeed, called facies. Ye. V. Shantser actually considers channel, flood-plain, and oxbow alluvium as "groups of facies". He distinguishes, for example, in channel alluvia the "facies" of near-channel shoals, bars, race and perluvial "facies". However, such fine genetic subdivisions are principal objects of study only in specialized investigations which are still infrequent. Hence, it is hardly worth while to attach to them the exceptionally popular term "facies" narrowing, thereby, its significance.

Analysis of the factual material gathered in the process of numerous exploratory and prospecting operations conducted in alluvial gold placers makes it possible to maintain that the three-member system of alluvial facies structure, as developed by Ye. V. Shantser, requires certain amplifications. The necessity for such amplification becomes evident upon consideration of the structural characteristics of alluvium as related to various dynamic phases.

## The Basic Characteristics of the Dynamic Phases of River Valleys and Alluvial Deposits

It is well known that fluvial alluvial deposits in various stages of development differ very substantially from each other. This was first pointed out by V. V. Lamakin [7] who has divided

[1] Fatsii, Dinamicheskiye fazy i svity allyuviya.
. 77 - 90.

alluvial deposits into three dynamic phases: "instrative", "perstrative", and "constrative". Regrettably, this structural scheme for alluvium is not as popular as that proposed by Ye. V. Shantser. Yet, it reflects the essential structural characteristics of alluvial layers, without a correct understanding of which it is almost impossible to speak about classification of alluvium into facies. The concept of the dynamic phases of alluvium is particularly important for studies of the formation of alluvial placers. However, V.V. Lomakin's position calls for more specific definitions.

The state of dynamic equilibrium in river valleys, according to V.V. Lomakin's interpretation [8], represents only the transition from downcutting to aggradation, while perstrative alluvium which corresponds to this state represents the transition from instrative to constrative alluvium. In reality both the corrading and the alluvium-accumulating rivers strive to achieve, and do achieve, a state of dynamic equilibrium which is maintained when the amounts of loose material supplied to the stream and carried away by it are well balanced. The state of dynamic equilibrium is, perhaps, more commonly observed than the processes of corrasion and aggradation even in rivers of mountain regions. This interpretation of the conditions governing the geomorphological equilibrium of river valleys may not be universally accepted yet, but it is sufficiently well substantiated in a number of relatively recent works of our own and foreign authors [3, 5, 6, 10, 14, 15].

V.V. Lamakin believes that the "floor of alluvium in a perstrative section is approximately at the level of the river bottom" [8, p. 169], and that "here all of the alluvial mass belonging to a given cycle of the river's activity remains within the sphere of its immediate influence" (Ibid, p. 167). The same opinion is shared by Ye. V. Shantser [12], S. A. Yakovlev [13], and many others. But prospecting operations in auriferous regions have long since established the fact that there is always an alluvial layer in the equilibrium sections of river valleys under the bottom of the river and is not affected by the activity of the water current even during maximum freshets. It is precisely to this alluvial layer that the richest of all alluvial placers - the valley placers - are confined. In determining the causes for the formation of this layer, Yu. A. Bilibin wrote: "It is difficult to assume that every mountainous country after a period of uplift causing a deepening of the valleys, could have suffered a subsidence necessary for these valleys to be filled with river sediments" [1, p. 141].

It should be noted also that without the formation of an alluvial layer, preventing the river channel from coming into contact with the bedrocks, the process of corrasion genera[lly] never stops since, of course, there is no equilibrium of any kind between the power of the flow and the resistance of rocks when there is indefinitely continuing action by the stream upo[n] its own bed.

The main reason for the formation of such an alluvial layer during the process of transitio[n] from corrasion to the state of dynamic equilibrium, is the widening of the valley and formati[on] of a flood plain. This involves an extension of the channel's length and a decrease of gradient due to the formation of meanders, an increase in the dissection of the interfluvial slopes, a reduction in freshet flow rates, and other phenomena producing a single-valued effect on the balance of the unconsolidated material in the river.

V.V. Lamakin's theories concerning the nature of dynamic equilibrium in river valleys and the mode of perstrative alluvium deposition are, apparently, also related to his views concerning which different phases of alluvial deposits are believed to replace one another as the river passes from one stage of development to another. In fact, however, only the beginning of the corrading process leads to the elimination (sometimes incompletes) of the previously existing alluvium, and to its replacement by instrative alluvium. Both perstrative, and constrative, alluvia, as a rule, do not replace other phases and are deposited on top of them. Consequently, in "normal" alluvial sections of rivers in a state of equilibrium, one can usually distinctly discern the deposits of two phases: the instrative phase deposited directly on the bedrocks (on the subterrane), and the perstrative phase resting on the instrative alluvium (Figures 1 and 3). In valleys containing alluvial deposits of considerable thic[k]ness, formations of all three phases generally are observed. In certain cases the alternation of these phases, reflecting the history of the relief development and alluvium formation, ma[y] be very complex (Figure 4).

Instrative alluvium. The corrosion process coinciding with the accumulation of instrative alluvium is characterized by a negative balance of loose material. Rivers carry away more loose material than they receive from the corrading sections of river valleys. Therefore the accumulation of alluvium within their limits is only temporary in the majority of case[s]. Instrative flood plains are usually insignificant in width (Figure 2) and only in exceptional cases are commensurate with the flood plains of sections in equilibrium (Figure 1). All of them have thin layers of alluvium which are completely exposed to the effects of water action, are very rapidly transformed into low terraces at intermediate levels (Figure 1), and are subsequently destroyed. Corrosion sections are encountered where there are no

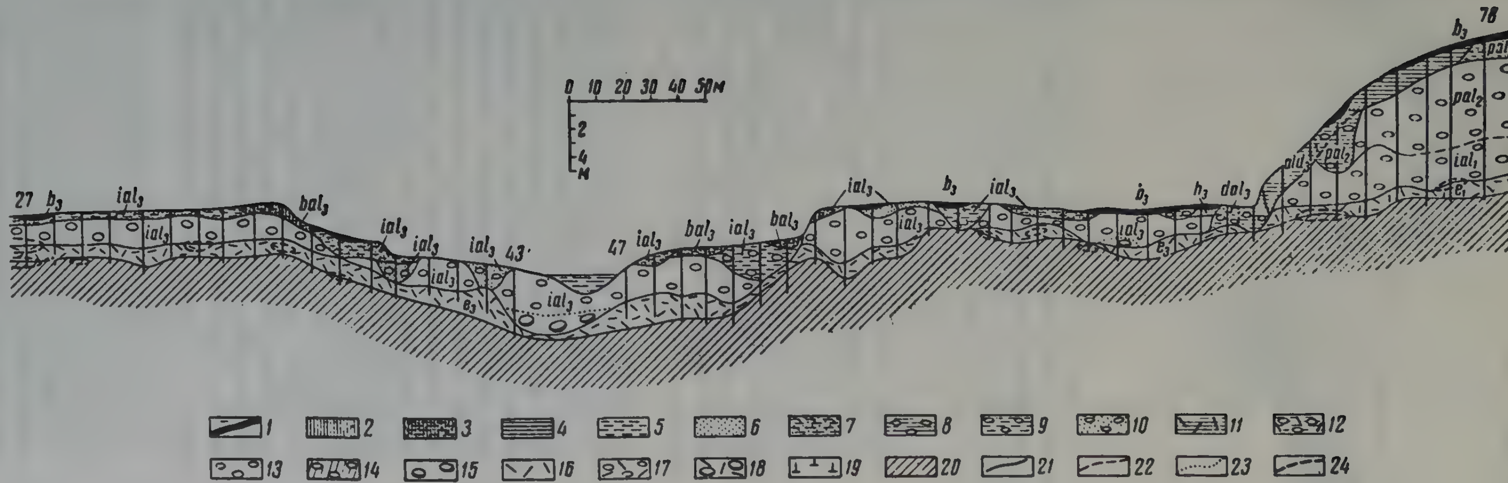


FIGURE 1. Instrative flood plain of the Ten'ka River (right tributary of the Kolyma). Section of consolidated deposits along survey line 386, prospect holes 27-78.

1 - soil, 2 - peat, 3 - sandy-silt peat, 4 - loam and argillaceous sand, 5 - silt, 6 - sand, 7 - silty sand; 8 - pebbly-argillaceous deposits (loam or argillaceous sand containing pebbles and gravel); 9 - pebbly silt deposits (silt and silty sand with pebbles and gravel), 10 - pebbly arenaceous deposits (sand with pebbles and gravel), 11 - deposits of detritus and clay (clay, loam, or argillaceous sand with detritus and gruss), 12 - pebbly-detrital-muddy deposits (silt or silty sand with pebbles, detritus, gravel, and grus), 13 - pebble (pebbles and gravel with silt, sand with detritus and grus), 14 - pebbly-argillaceous deposits (pebbles and gravel with loam or clayey sand), 15 - boulder beds (boulders, pebbles and gravel with any kind of fine material), 16 - detrital deposits (detritus, and grus with any kind of fine material), 17 - pebbly-detrital deposits(pebbles, detritus, gravel and grus with any kind of fine material), 18 - deposits of boulders and detritus (boulders, pebbles, detritus, gravel, and grus with any kind of fine material), 19 - icing deposits, 20 - bedrocks (sandy-clay shales of the Verkhoyansk complex), 21 - boundaries between formations, facies, and genetic types of deposits, 22 - the same boundaries but lithologically not expressed, 23 - boundaries between the lithological varieties of deposits belonging to the same facies, 24 - boundaries of zones of high concentration placer-gold. Figures over the surfaces of sections are the numbers of prospecting holes.

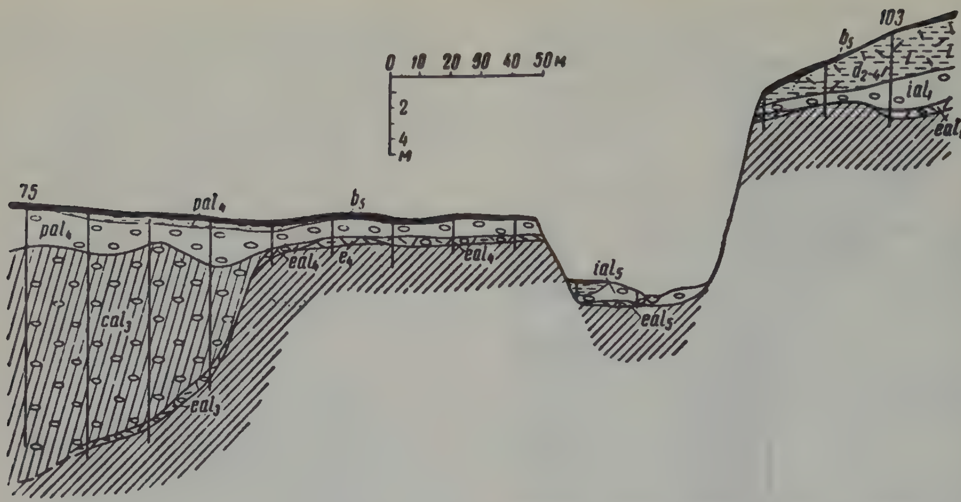


FIGURE 2. Instrative flood plain of the Bol'shoy Inyakan channel (right tributary of the Kolyma). Section of loose deposits along survey line 180, holes 75-103.

Symbols are the same as in Figure 1.

flood plains. Alluvium here is in a state of constant movement.

The feeble development of flood plains has the result that bottom-land and oxbow facies play practically no role in the formation of instrative alluvium. Their occurrence is rare and they are confined mainly to abnormally wide instrative flood plains (Figure 1). The instrative variety of bed facies is characterized by a number of specific features resulting from its formation during the downcutting process. In the first place, one should point out the presence of a considerable number of angular fragments, not rounded by the river, which get into instrative alluvium by rolling down the slopes that often abut on the channel, and from the bedrock bottom eroded by the river.

The second characteristic is the considerable coarseness of the material making up the instrative variety of the bed facies. In the bottom part of the same sections, instrative alluvium contains, as a rule, coarser pebbles than the overlying deposits of the bed facies of perstrative and constrative alluvium.

At the same time, instrative alluvium is distinguished by poor sorting, and clay particles may often be found in it along with coarse fragmentary material. Clayiness — "unelutriatedness" — is the third peculiarity of instrative bed-alluvium. Ye. V. Shantser [12] describes this phenomenon as the combining of bed and flood-plain alluvia into a single layer, and believes this to be a characteristic feature of mountain alluvium in general. It should be mentioned here, that the other features, which according to Ye. V. Shantser are peculiar to mountain alluvium — lack of regular succession of facies and insignificant thickness — are characteristic precisely of the instrative alluvium of mountain rivers, and are not so very typical of the perstrative alluvium of these rivers.

The fourth peculiarity of instrative bed alluvium is the largest coarse accumulations of heavy minerals producing commercial placer deposits are localized in its lower horizons. These accumulations never are as large in perstrative and constrative alluvial deposits. This phenomenon is attributable to the low mobility of placer-forming minerals. Every corrosive action of the river leads to the reworking and elutriation of the previously formed alluvial deposits. The heavy minerals contributed to the alluvium by the slope deposits are not carried away during corrasion, and they concentrate in the instrative alluvium, gradually forming very considerable accumulations. Of course, this latter characteristic of instrative alluvium may be manifested only in the river valleys, whose slopes furnish a sufficient quantity of minerals to form placer deposits.

In those cases when the amplitude of corrasion is inferior to the thickness of the previously accumulated alluvium, the instrative deposits are found to be resting not on bedrocks but on deposits of other phases. It goes without saying that such lithologic characteristics as high proportion of unrounded fragments, the generally greater coarseness of the

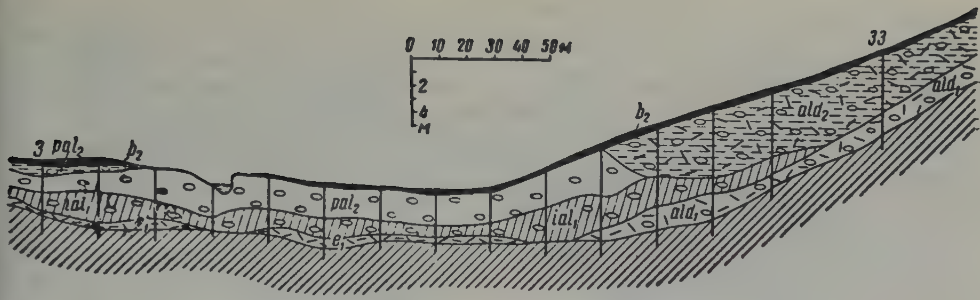


FIGURE 3. Perstrative flood plain of Budennyy brook (left tributary of the Ten'ka). Section of unconsolidated deposits along line 68, holes 3-33.

Symbols are the same as in Figure 1.

material and its poor sorting, cannot be manifested in instrative alluvium produced by rewashing of deposits no longer possessing these characteristics. Accumulations of concentrated minerals constituting commercial placers may frequently be encountered in such kind of instrative alluvium. These are the, so called, placers with "a false bottom" (Figure 4). However, they are usually not as rich as those localized in instrative alluvium overlying true bedrock [1].

Perstrative alluvium is distinguishable from instrative deposits, and quite often also from the constrative variety, by the more rounded coarse material, total, or almost total, absence of angular fragments, and a high degree of sorting.

In comparing the structural peculiarities of perstrative alluvium in the rivers of gold mining mountains regions with the structural peculiarities of the plains river alluvium described in detail by Ye. V. Shantser [12], one cannot fail to note that there are no fundamental differences between these types of alluvium.

The facies structure of the fluvial perstrative alluvium of mountainous regions is distinguishable only through the somewhat more clearly pronounced prevalence of the bed facies over the flood-plain and oxbow facies. The latter often are completely absent in its sections, but, as may be seen from the accompanying illustrations, this absence is not at all mandatory or typical.

A very considerable contents of coarse material (gravel, pebbles, boulders) in the perstrative alluvium of mountain rivers, as compared with the alluvium of plains rivers, is a specific feature characterizing the lithologic peculiarities of the former. In the deposits of the bed facies this coarse material is, as a rule, predominant; in the oxbow-facies deposits it may also be encountered rather frequently, although always in lesser amounts (Figure 3 and 4). The flood-plain facies contain an insignificant amount of coarse material only in rare cases, but these materials are more often represented by sandy rather than clay material.

Often, considerable concentrations of heavy minerals are accumulated in the bottom sections of bed facies deposits of perstrative alluvium. Sometimes they occur as placers of commercial significance, but they almost never attain the proportions of placers located at the bottom of instrative alluvial horizons.

The perstrative alluvium of mountain rivers is always entirely within the sphere of action of rivers in a state of dynamic equilibrium. It is precisely its "normal" thickness which can be determined as "the difference between the levels of an average flood and the bottom of average-depth reaches" [12, p. 213]. But, as stated earlier, perstrative alluvium does not lie directly on the bedrock. Consequently, the total "normal" thickness of alluvium in rivers in a state of equilibrium, at least in mountain regions, always exceeds this value.

The peculiarities of the facies structure and the lithologic characteristics of perstrative alluvium are due to the fact that it is formed by rewashing and reworking of the alluvium belonging to other phases by a river occupying an approximately identical vertical position throughout the entire stage of dynamic equilibrium. When this equilibrium is established after the processof alluvium accumulation, the deposition of perstrative alluvium upon the constrative phase requires no special explanation. When equilibrium ensues as a result of downcutting by the rivers the formation of perstrative alluvium is, evidently, preceded by a sharp increase in the thickness of instrative alluvium caused by the phenomena which accompany the transition from corrasion

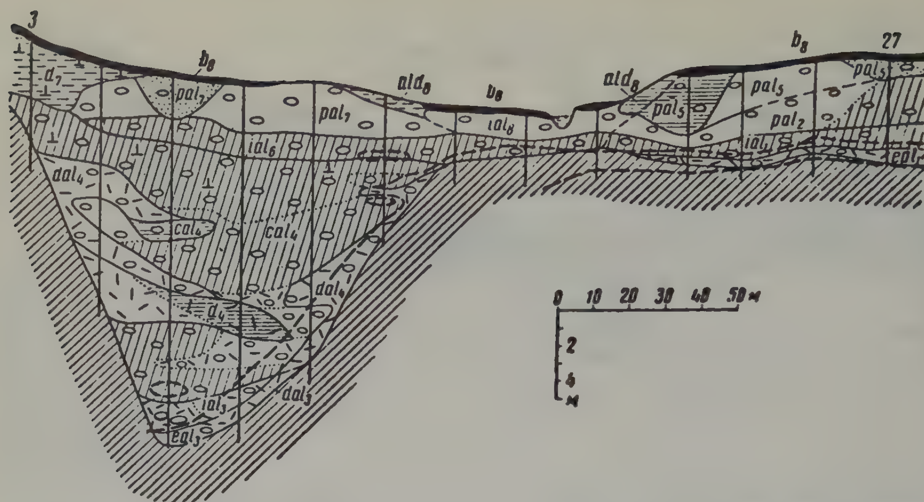

FIGURE 4. Section of unconsolidated deposits in the valley of Pavlika creek (the Ten'ka basin) along line 6, holes 3-27.

Symbols are the same as in Figure 1.

to dynamic equilibrium. The lower horizons of instrative alluvium form a layer which is stable even during maximum flooding, which protects the bedrocks from the erosive action of the water, and they retain all of their lithological and facies characteristics. The re-washing and reworking of the top horizons lead to the formation of perstrative alluvium on top of the instrative alluvial deposits. Those occasional cases, when the alluvium in rivers in the state of equilibrium cannot be differentiated according to lithological characteristics into instrative and perstrative phases are apparently, not always attributable to the inferior quality of the primary prospecting logs. Doubtless some of this is due to the recently established dynamic equilibrium and the youthfulness of perstrative alluvium which has not yet acquired its characteristic features.

Numerous publications dealing with the prospecting of placer deposits speak of the fact that the occurrence of instrative alluvium under the perstrative deposits in mountain rivers which have reached the stage of dynamic equilibrium after downcutting, is a rule for which there are practically no exceptions. Only when the rivers continue to widen their banks, undermining the bedrock slopes during the stage of dynamic equilibrium, does the horizon of perstrative alluvium extend beyond the underlying instrative formation and settle directly over the subterrane, or upon eluvial and deluvial deposits (Figure 2).

Despite the lack of similar information on the structure of the alluvium in plains rivers, I am convinced that this rule also applies. The views held by Ye. V. Shantser, V. V. Lamakin, and many others, to the effect that all alluvial deposits in the equilibrium sections of river valleys subjected to the action of a stream whose channel is immediately contiguous to the bedrock, seem to me to be erroneous. Sections having such alluvial structure cannot be in a state of equilibrium and, obviously, must be considered as instrative.

Constrative alluvium, formed during aggradation usually covers the deposits of rivers in the state of equilibrium and is deposited on perstrative alluvium. However, a "flooding" by the alluvium from river-valley slopes leads to the formation of constrative alluvium on the bedrocks or on the unconsolidated deposits of non-alluvial origin developed on the slopes. When the accumulation process includes the degrading sections of the river valleys, the constrative alluvium settles directly on top of the instrative alluvium (Figure 4).

V. V. Lamakin [8] considers the predominance of the flood-plain facies over the channel facies as one of the basic characteristics of constrative alluvium. The fallibility of this point of view was conclusively proved by Ye. V. Shantser who demonstrated that channel alluvium is much more prevalent in constrative strata than is that of all other facies. "Although the suspended sediments actually predominate in the total volume of sediment discharge — writes Ye. V. Shantser [12, p. 243) — nevertheless, the overwhelming majority of detritus, even under affluent conditions, is carried out by the river

om the valley. The subordinate, third-te role played by the flood-plain facies in e structure of the majority of alluvial for-ations becomes, therefore, comprehensible, gardless of the tectonic conditions of their position".

This position agrees very well with the ospecting data on the structure of constrative luvium in auriferous regions. In the sections constrative alluvium in auriferous regions. the sections of constrative alluvium, de-osits of flood-plain and oxbow facies are sually found as isolated lenses. They gen-rally occupy a subordinate position and do ot differ in their lithological characteristics om the flood-plain and oxbow facies of erstrative alluvium.

The constrative variety of bed facies pre-ominating in these strata is formed under con-itions of aggradation which hinder repeated ewashing. Consequently, in terms of its thologic characteristics, it more closely pproximates the instrative than the perstra-ve alluvium. Thus, poor sorting is quite ypical of it — the clayiness of the component ebble beds. Frequently this variety is dis-nguishable by the noticeable presence of un-ounded detritus. However, when unconsolidated aterial is supplied to the build-up area from n up-river section and not from its slopes, is lithologic characteristic may be entirely bsent. Being bedded in perstrative alluvium, onstrative bed alluvium usually is conspicuous y its greater coarseness of material. But is distinction may be diametrically opposite. henever accumulation is caused by an in-reased supply of unconsolidated material the river, the constrative allusium is gen-rally coarser than that of the underlying erstrative bed. Whenever aggradation begins s a result of diminishing force of the current, he coarseness of the material comprising the onstrative bed alluvium decreases in com-arison with the material of perstrative alluv-um. In certain cases the constrative bed lluvium in mountain rivers is altogether levoid of coarse material and approximates he flat-land type of bed alluvium in respect o lithologic characteristics.

The heavy concentrate minerals usually re dispersed throughout the entire layer of onstrative bed alluvium and very rarely orm insignificant concentrations which, as rule, have no commercial importance.

## Subterrane and Cover Facies of Alluvium

Even a first acquantance with the materials resulting from prospecting operations carried out in gold placers shows that there are no fundamental distinctions between the alluvia of mountain rivers and those of plains regions. Those difference that actually exist consist mainly in that all mountain river facies are represented by coarser clastic material.

At the same time the differences between instrative, perstrative, and constrative alluvium — even when they are relatively poorly reflected in lithological characteristics — are very important for a correct understanding of the history of relief formation, alluvial deposits, and placer deposits of commercial minerals. I, therefore, cannot agree with Ye.V. Shantser's assertion that his proposed "normal classification of alluvium . . . is valid for all three of the dynamic phases proposed by V.V. Lamakin". [12, p. 37].

Particularly noteworthy and important are the genetic and lithologic differences between the instrative, perstrative, and constrative varieties of bed alluvium, which obviously constitutes the principal facies prevalent in most alluvial strata. The essential nature of these distinctions induces me to advance a suggestion: to consider these three varieties as independent facies of alluvium, since they not only fit perfectly the definitions of facies of unconsolidated deposits as described above, but are also taxonomically analogous to the previously identified alluvial facies.

For instrative alluvium which is present in the thalweg[2] portion of any river valley, and which rests on bedrock (known in placer geology as "subterranes"), I suggest the term "subterrane facies" [5, 6]. For the constrative variety of bed alluvium the most appropriate designation, I feel, is "cover facies", which reflects its position in the sections of thick alluvial strata.

The term "bed facies" should be retained to designate perstrative alluvium, the study of which is the basis for Ye.V. Shantser's classification. It is true that this term is not in the same category as those referred to above, but it has become so popular that it is hardly possible to change it at the present time.

The subdivision of alluvium into dynamic phases might be reflected to advantage in the genetic indices applicable in geologic sections and used to designate sequences in this paper.

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[2]The term "Thalweg" has been used for a long time in prospecting practice to designate the line connecting not "the deepest parts of the channel" [4], but the lowest sections along the bottom of a valley. This change in terminology is certainly advantageous, since it gives a definite name to a very important element in the structure of river valleys and eliminates the superfluous synonym for the term "farvater" (German "fahrwasser";—channel in English).

## Alluvial Deposits

The basic subdivisions used in local stratigraphic scales is the formation: "a complex of rocks distinguishable by definite characteristics, formed within the limits of a given region under definite conditions, and occupying a definite stratigraphic position in the given region" [4]. Formations in unconsolidated deposits should also be identified according to this definition. The natural age boundaries in such formations are determinable by the changes occurring during the process of formation of the unconsolidated deposits caused by corresponding modifications in the orientation or rate of development of the relief-forming processes.

Formations of unconsolidated deposits may include formations of different origin. However, alluvium is of such a genetic type that its study usually is of decisive importance in developing stratigraphic maps of unconsolidated deposits. Rivers are known to be relief- and rock-formation agents, and they are very sensitive to all changes in external conditions. Because of this, the structural peculiarities of alluvial deposits reflect all details of the history of geologic development.

The most essential modifications of external conditions lead to changes in the relief-forming processes in rivers. Each such change governs the formation of alluvium belonging to a definite dynamic phase. Thus, the boundaries between the dynamic phases of alluvium must be considered as the natural stratigraphic boundaries of alluvial formations. When alluvial deposits are confined to different terrace levels, these stratigraphic boundaries become particularly clearly manifested.

It should be noted that the reaction of fluvial relief-forming processes to changing external conditions in a number of cases does not facilitate, but rather, complicates considerably, the task of the stratigraphic differentiation of unconsolidated deposits. The rapid change of relief-forming processes, in terms of time and in space, causes the sections of alluvial deposits, located even a short distance apart, to display sometimes a rather dissimilar structure. This, of course, hampers the correlation of sequences, identification of formations, and other stratigraphic units. In most sections of alluvial deposits it is possible to identify several stratigraphic units. But, in order to produce a local stratigraphic scale and distinguish formations, comparison and study of an entire series of such sections relative to a more or less extensive area are required. The stratigraphic units in individual sections may be referred to as formations as tentative identification only, and should be designated by index numbers as was done in the case of the sections included in this paper.

It is well known that formations of bedrock must necessarily be named in accordance with their proper geographic location [11]. Similar geographic names should be assigned to formations of unconsolidated deposits identified on the basis of comparison and correlation of sections, as was recommended by Yu. A. Bilibin [2].

Of course, the formations of unconsolidated deposits belonging mostly to the Quaternary system are thinner and cover less area than do bedrock formations, just as the Quaternary is less widespread than the other systems. This, nevertheless, should not affect the principles of identification and study of these stratigraphic units.

Formations of unconsolidated deposits, like bedrock formations, can be combined into larger subdivisions, such as series. Their boundaries should coincide with the more substantial changes in the character of sedimentation associated with sharp climatic changes, alterations of the general conditions of tectonic movements, etc.

The creation of well-substantiated, local stratigraphic scales is mandatory before determinations can be made of the position of any of the deposit in the general stratigraphic scheme. In studies of unconsolidated deposits this rule is, regrettably, often disregarded. Considerations relative to the amount and sequence of glaciations, the correspondence of fluvial terrace elevations to specific age boundaries, the coincidence of changes in the character of erosion processes with definite geologic data, etc., dominate in such cases over the factual material. These are the factors which become the main source of errors and differences affecting the stratigraphic maps of unconsolidated deposits.

The lithologic characteristics of alluvial and other unconsolidated deposits belonging to varying formations, their thickness, typical position in sections, and other characteristic features, make it possible sometimes to reconstruct, in detail, the history of sedimentation and relief formation. The brief historical reviews of the formation of unconsolidated deposits in several fluvial valleys described in the following section may serve as an example of such an analysis.

## The History of Formation of the Relief and Loose Deposits in a Few River Valleys in one of the Regions of Northwestern USSR

Analysis of the structural characteristics of unconsolidated deposits represented in the preceding sections (Figure 1-4), enables us to compile short historical descriptions of their formation which supplement and clarify these

sections. It should be noted that no comparison of these sections with each other, and with other sections, has been made, and that the "formations" in them are identified conditionally. It may well be that a number of these formations do not appear in these sections, and that some of the identified "formations" may, on the other hand, not be characteristic of the region as a whole.

Ten'ka River. The oldest deposits in the section (Figure 1) are the pebble beds of subterrane facies ($ial_1$) and the subjacent detrital eluvium ($e_1$) of "formation" 1, at the base of the terrace on the right.

During the stage of dynamic equilibrium which has replaced the degrading process, formed pebble bed facies ($pal_2$), pebbly argillaceous deposits belonging to the oxbow facies ($pal_2$), and the flood-plain facies silty sand ($pal_2$) were formed — all of them constituting "formation" 2. The over-all thickness of the Ten'ka River flood plain is 10 m, which corresponds to its "normal" thickness of alluvium in the equilibrium section starting a few kilometers above the given section.

At present, the downcutting which replaced the equilibrium stage has deepened the valley of the Ten'ka River by some 10-12 meters, and, judging by the structure of the present-day flood plain, has not yet stopped. Characteristic of the corrading process in the Ten'ka valley is the very important role played by horizontal shifting of the channel. As a result, the instrative flood plain is quite wide and has a flat, step-like surface. "Formation" 3, of which it is composed, is represented not only by detrital eluvium ($e_3$), boulder deposits and pebble beds of subterrane facies ($ial_3$), but also by sand, silty sand, pebbly-arenaceous and pebbly-silty deposits of the oxbow and flood-plain facies ($ial_3$). The deposits of flood-plain and oxbow facies are partially replaced by biogenic-alluvial and biogenic deposits: sandy silt peat ($bal_3$) and peat ($b_3$). The deposits comprising the lower, near-channel stage of the flood-plain were, apparently, formed somewhat later than the deposits of the upper stage. However, since the downcutting process continued, and there were no changes in the conditions affecting the formation of the deposits, there is no justification for "formation" 3 to be divided into two independent "formations". "Formation" 3 also includes the loam, argillaceous sand, and pebbly-clay deposits of the alluvial-deluvial facies of the terraced spurs ($ald_3$), and originated as a result of the shifting of the allvuial deposits from the right terrace produced by the processes of slope denudation. The contact of these alluvial-deluvial deposits with the flood-plain alluvium represents, it seems, a pattern of complex interstratification. In the original records it was recorded as consisting of pebbly, argillaceous and pebbly silt deposits, in the section it is considered as undifferentiated deluvial-alluvial deposits ($dal_3$). The soil ($b3$) is also included in "formation" 3.

Bol'shoy Inyakan Creek. "Formation" 1, the oldest in the section (Figure 2), is represented by pebble beds of the subterrane facies ($ial_1$) and pebbly-detrital eluvial-alluvial deposits ($eal_1$) forming the base of the right terrace.

"Formation" 1 was, in all probability, covered by perstrative alluvium which later was totally eroded in the course of subsequent relief development. The first development stage (after the formation of "formation" 1) fixed in this section was the cutting of the Bol'shoy Inyakan creek to a depth of not less than 25 m, which cut a canyon in the left part of the section. The instrative alluvium formed during the cutting of the canyon was not exposed by prospect holes. However, the deluvial material which covers the deposits of "formation" 1 on the right terrace, and which is represented by silt and detrital-silty deposits, must have been, apparently, partially synchronous with this instrative alluvium. The formation of deluvial deposits, evidently, also must have continued later — during the formation of "formations 3 and 4, as this reflected in its index ($d_{2-4}$).

The next relief development stage observable in the section was the accumulation of alluvium and partial burial of the canyon. "Formation" 3 which was formed at this time is represented by the clayey pebble deposits of the cover facies ($cal_3$) and the eluvial-alluvial, pebbly-detrital deposits ($eal_3$).

The aggradation process terminated when the surface of the Bol'shoy Inyakan floodplain attained the elevation of the present left terrace. The ensuing state of dynamic equilibrium was accompanied by the process of fluvial abrasion — the Bol'shoy Inyakan was scouring its right bank, widening the flood plain, and destroying the right terrace. This period saw the formation of "formation" 4, represented by pebble bed facies ($pal_4$), silt of the flood-plain facies ($pal_4$), eluvial-alluvial deposits of pebbly detritus ($eal_4$), and detrital eluvium ($e_4$). Since fluvial abrasion continued after the establishment of dynamic equilibrium, the deposits of the bed facies in the central part of the section are separated from the bedrock by only a thin layer of eluvial-alluvial or eluvial deposits.

Dynamic equilibrium was again replaced by another period of erosion during which the Bol'shoy Inyakan valley was deepened for 5-6 m. This still continues at the present time. "Formation" 5, which is presently being formed, is represented by pebble beds of the subterrane facies ($ial_5$), oxbow silt ($ial_5$), eluvial-alluvial deposits of pebbly detritus ($eal_5$), and soil ($b_5$).

Budennogo Creek. Section (Figure 3) reflects only the most recent formative stages of the Budennogo Creek valley and the unconsolidated deposits filling it. "Formation" 1 is represented by detrital eluvium ($e_1$), pebbly clay deposits of subterrane facies ($ial_2$), and the beds of pebbles and detritus belonging to the terraced-spur facies ($ald_1$). The presence of these spurs betrays the fact that there used to be a terrace on the right slope, which consisted of alluvial deposits. The destruction of this terrace by processes of slops denudation has actually lead to the formation of deposits of the terrace-spur facies. The formation of "formation" 1 deposits continued not only throughout the process of degradation, but also during fluvial abrasion (widening of the valley) which served as the transition stage between downcutting and dynamic equilibrium.

"Formation" 2, represented by pebble beds of the bed facies ($pal_2$), pebbly silt deposits of the flood-plain (possibly, oxbow) facies (pal ($pal_2$), and the soil ($b_2$), — was formed during the dynamic equilibrium stage, continuing to the present time. The deposits belonging to the terraced-spur facies were accumulated as a result of continuing destruction of the right terrace, while the deposits of alluvial facies are the product of protracted rewashing of the deposits belonging to the subterrane facies and partly to that of the terraced spurs.

Pavlik Creek. Judging by the fact that the gold-bearing layer of the right terrace (Figure 4) extends along the slope of the buried canyon and, apparently, constitutes an older formation than this canyon, the deposits resting on the terrace at the bottom of the unconsolidated stratum are the oldest formations in the section. "Formation"1 is represented by eluvial-alluvial deposits of pebbles and detritus ($eal_1$) and argillaceous-pebbly deposits of the subterrane facies ($ial_1$).

The great width of the right terrace indicates that a perstrative flood plain must have existed at its level. This justifies the assignment of the pebble beds and the argillaceous-pebbly deposits overlying "formation" 1 to the bed facies ($pal_2$) of "formation" 2. We can not exclude the possibility, however, that the deposits related to "formations" 1 and 2 were actually formed after the burial of the canyon.

During the process of the corrasion which was responsible for the canyon carving, there the following components of "formation" 3 were laid down: the deposits of boulders and detritus and those of pebbles and detritus belonging to the subterrane facies ($ial_3$), the pebbly-detrital eluvial-alluvial ($eal_3$) and the deluvial-alluvial deposits ($dal_3$).

Degradation gave way not to dynamic equilibrium but to accumulation of alluvium which caused the burial of the canyon under the argillaceous-pebbly, pebbly-detrital, and pebbly deposits of the capping facies ($cal_4$), the pebbly clay deposits of oxbow facies ($cal_4$), the pebbly-detrital talus-alluvial ($dal_4$), detrital and detrital-argillaceous talus ($d_4$) deposits of "formation" 4. The glaciated portion of the argillaceous-pebbly deposits is, in all probability, syngenetic.

Dynamic equilibrium, it seems, must have begun after both the canyon and the right terrace were buried under the unconsolidated deposits. At this time the pebble beds belonging to the channel facies ($pal_5$) and the pebbly clay and pebbly sand deposits of oxbow facies ($pal_5$) comprising "formation" 5, were deposited.

Dynamic equilibrium was again replaced by down cutting resulting in the formation of argillaceous-pebbly deposits of the subterrane facies ($ial_6$) of "formation" 6, distinguishable from the subjacent deposits of the capping facies of "formation" 4 not only by the absence of glaciation, but also by the much smaller amount of cementation. The boundary between "formations" 6 and 1 was traced tentatively, since the original records show no differences between them. It should be stated here that "formation" 1 differs from "formation" 6 by the absence of eluvial-alluvial deposits and the great thickness of the gold-bearing layer "inserted" much deeper into the fissures of the bed rock.

During the subsequent dynamic equilibrium stage, the pebble beds of the bed facies ($pal_7$), the pebbly-sand deposits of the oxbow facies ($pal_7$), and the glaciated silty deluvial deposits ($d_7$) of "formation" 7, were deposited.

The most recent low-amplitude downcutting may be judged mainly on the basis of the relief character, since the pebble beds of the subterrane facies ($ial_8$) of "formation" 8 are practically undistinguishable from the bed alluvium of "formation" 7. The silty and pebbly clay deposits of the terraced-spur facies ($ald_8$) and the soil ($b_3$) were formed simultaneous with the pebble beds of "formation" 8.

## CONCLUSIONS

The subdivision of alluvium into dynamic phases, as proposed by V.V. Lamakin [7], is of great importance for a correct understanding of the principal structural characteristics of alluvial deposits.

The destruction of the pre-existent alluvium belonging to different phases occurs only with the formation of instrative alluvium. Perstrative and constrative alluvia in the process of their formation do not replace the previously existing alluvial phases, but cover them up.

The definition of "normal" thickness of alluvium as a difference between the elevations of average freshets and the bottom of average-depth reaches [12] is correct only with respect to perstrative alluvium. In view of the fact that in equilibrium rivers, perstrative alluvium is superposed on instrative deposits, the total "normal" thickness of these deposits, at least for the case of mountain rivers, is always greater than that calculated by Ye. V. Shantser's method [12].

There are no fundamental differences in the facies structures of plains and mountain river alluvia. Mountain-river alluvium is distinguishable only by the greater coarseness of the component material and somewhat less developed oxbow and flood-plain facies.

On the other hand, the distinctions in facies structure and lithologic characteristics of alluvium belonging to different phases are very considerable. They are particularly noticeable in the alluvium called by Ye. V. Shantser [12] bed alluvium. This makes it possible to identify in the bed alluvium characterized by Ye. V. Shantser, three facies: subterrane - in the instrative phase, bed - in the perstrative phase, and capping - in the constrative phase.

The presence in alluvial sections of deposits belonging to deposits belonging to different dynamic phases is determined by the changes in the character of fluvial relief-forming processes and, consequently, reflects the definite historical stages of geologic development. Thus, these deposits of various phases may also be considered as stratigraphic units - formations.

Assimilation and theoretical generalization of the vast material accumulated in the course of geologic prospecting operations in placer deposits will, no doubt, lead to very considerable contributions to the knowledge of the regularities governing the formation of alluvium.

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The All-Union Scientific-Research Institute of Gold and Rare Metals, Magadan

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# THE PROBLEM OF THE RELATIONSHIPS BETWEEN MARINE AND CONTINENTAL DEPOSITS IN THE LOWER AND MIDDLE VOLGA REGIONS[1]

by
Yu. M. Vasil'yev and P. V. Fedorov

The solution of the problem concerning the relationships between the marine Quaternary deposits of the Caspian Sea and the alluvial formations of the Volga is very important for the general problem of the comparison of the marine and continental deposits in the southeastern part of European USSR.

The Lower and Middle Volga regions, where these relationships must be clarified are well studied. Here the first stratigraphic scale was developed for the Quaternary deposits of the Caspian, and definite ideas were formulated by which the Khvalynsk maximal transgression was compared with the Volga terrace II and with the "Würm" glaciation of the Russian plain, the Khazar transgression - with terrace III: the "Riss" glaciation terrace, and the Baku — with the 4th: "Mindel" glaciation. However, enough factual material was recently accumulated to justify the introduction of certain corrections and amplifications into the existing concepts connected with this matter. The observations conducted by P.V. Fedorov [22] in 1951 along the right bank of the Volga from Syzran' to Astrakhan' have shown that the highest (48 m) Lower Khvalynsk terrace of the Caspian adjoins not terrace II, but Volga terrace III. M.N. Grishchenko arrived at the same opinion [5] on the basis of a comparison of the Volga and Don terraces.

In 1959 the authors of this paper jointly studied sections of the Quaternary deposits along the lower and middle Volga from Astrakhan' to Kuybyshev. Considered below are mainly the problems of the correlation of the Khvalynian marine terraces with the terraces of the Volga, and also the relationships between certain older alluvial and marine beds. The analysis is based on the data from 1959 observations and earlier materials.

The Baku, Khazar, and Khvalynsk deposits, stratigraphically similar to the corresponding layers of the entire Caspian basin, were identified on the basis of borehole logs and in natural outcrops in the lower Volga valley. The Novocaspian sediments occur on the southernmost tip of the region along the Caspian coast.

The Baku deposits are represented by thinly-bedded marine clay rocks of dark-grey and brownish colors containing subordinate layers of siltstones and a mollusk fauna characteristic of the entire Caspian basin: Didacna parvula Nal., D. catilus Eichw., and others. These deposits outcrop in a limited number of plays in the Volga valley (Chernyye Yar, Kap Kapustin Yar, and other villages), and were discovered in many boring's outside its confines. In the region of Lake Baskunchak the Baku deposits occur in the coastal facies of shingle and coquina beds. At the top of the Baku stage continental formations may be occasionally observed along the Volga.

On rocks of the Baku stage, showing distinct traces of erosion, there are light-yellow, obliquely laminated, alluvial sands grading upward into a layer of grey and dark-grey, thinly-bedded clays with bands of sand which contain an abundance of fresh-water fauna (Unio Planorbis, Sphaerium, Corbicula fluminalis Müll.) and remains of vegetation. In the lower reaches of the Volga, starting at the village of Chernyy Yar, these clays and the subordinate sand layers contain a large variety of Lower Khazar mollusk fauna: Didacna subpyramidata Prav., D. pallasi Prav., D. paleotrigonoides Fed. The alluvial sands at the bottom of this layer, known as the Chernoyarsk sands, contain, according to V.I. Gromov's works [6, 7], the remains of mammals belonging to the Khazar complex: Elephas trogontherii Pohl., Bison priscus var. longicornis V. Grom, Camelus knoblochi Nehr., Elasmotherium sibiricum Fisch. The facies character of the overlying dark-grey clays permits them to be considered as oxbow-lake deposits which, further south, merge with the freshened Lower Khazar marine sediments. This fact is conclusively evidenced by the afore-mentioned mollusk fauna, similar to that of the Lower

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[1] K voprosy o sootnoshenii morskikh i kontinental'nykh otlozheniy nizhnego i srednego povolzh'ya. pp. 91 - 99.

Khazar deposits in Dagestan, Azerbaydzhan, and Turkmeniya.

Higher in this stratum one observes a predominance of chocolate-brown clays overlain by a very characteristic horizon of unstratified, lumpy, reddish and reddish-brown loams in which are buried meadow-bog-type soils. These loams are full of crystals and concretions of gypsum. Their tops are covered with frost fissures, the rocks are disturbed by frost heaves. The entire layer represents a single alluvial and alluvial-marine sedimentary complex, which is made up, at the base, of fluvial sands passing upward into oxbow alluvium, which is replaced in the south by the marine and alluvial-marine Lower-Khazar sediments.

Above the sharply scoured top of the Lower Khazar deposits there is a younger alluvial formation at the bottom of which, starting at the village of Nikol'skoye and farther south, are wedged brakish-water, laminated, argillaceous and arenaceous-argillaceous sediments containing a transitional assemblage of mollusk fauna. Included here are shells, still approximating the Khazar stage (Didacna subovalis Prav., D. ex. gr. surachanica Andrus., D. ex. gr. crassa Eichw.), and also the typically Khvalynsk forms, (Didacna cristata Bog., D. ebersini Fed.), which are clearly prevalent. In addition, one also finds many Monodacna caspia Eichw. These deposits belong to the Khazar stage and are identified by P. V. Fedorov [21, 22] as Upper-Khazar. They are underlain by obliquely-laminated sands in the form of lenses and bands.

The top of the Upper Khazar clay deposits is often eroded and are abruptly and unconformably overlain by sands. In a number of places, however, the underlying clays alternate with the covering sands and the former rather gradually grade into the latter. These sediment relationships attest to the estuarine and deltaic conditions of sedimentation. The light, almost white, sands covering, and sometimes underlying, the Upper Khazar brakish-water sediments are characterized by cross bedding and, apparently, constitute the bed facies of the alluvium. Further upward, they gradually become more clayey and grade into sandy and loess-like loams. In tracing this entire formation up-stream along the Volga, one gains the conviction that it represents a single complex, the individual components of which mutually grade into each other or the facies replace one another. Thus, in the region of Stalingrad (Raygorod, Srednyaya Akhtuba, and so on), we deal with a single alluvial formation which begins at the bottom with the bed facies and finishes at the top with sandy-loamy, loess-like formations known in the literature as "Atelian loams".

The Atelian formation was identified by P. A. Pravoslavlev [19] as an independent stratigraph[illegible] unit, in which he included not only the loess-like loams and sandy loams, but also the subjacent, obliquely laminated alluvial sands associated with the former by gradational contacts. In subscribing to P. A. Pravoslavlev's opinion, we feel that the isolation in the Volga Quaternary section of the Atelian continental formation, presented by alluvial sands and loess-like sandy loams and loams of different origin, but everywhere covered by Lower Khvalynsk marine layers, is wholly justified and expedient. Considering the significant erosion separating this suite (including the mentioned brakish-water sediments) from the top of the Lower Khazar deposits, the stratigraphic unity of the entire Atelian formation, and the absence of a major hiatus between it and the incumbent Lower Khvalynsk marine sediments, it is possible to speak of the greater stratigraphic similarity of the "Upper Khazar" marine layers in the Lower Volga regions to the Khvalynsk stage, than to the Lower Khazar stratum. It would probably be correct to compare these sediments to the "Ghirkanian beds" of G. I. Goretskiy [3] or to the "Lower Khvalynsk beds" of G. I. Popov [18] underlying the Gudilovian ("Bourtassian") sediments and overlying the Karangatian marine beds in the Manych valley.

On the basis of the data from the Lower Volg[illegible] section it is possible to surmise that the "Upper Khazar" marine beds and their alluvial analogs are associated with the transgression of the Caspian which immediately preceded the maximum Lower Khvalynsk transgression and was separated by a deep regression from the Lower Khazar transgression. Nowhere in the section of this section are there any significant discontinuities. Everywhere the cross-bedded sands grade upward into dusty dands, sandy loams, and loess-like loams.

Thus, in setting up the problem, one may say that the brakish-water sediments in the lower Volga region, usually referred to as Upper Khazar, should no longer be assigned to the Khazar stage, but to a younger formation which should retain its original designation, suggested by P. A. Pravoslavlev, the Atelian formation. The brakish-water sediments are the lowermost section of this formation.

In the lower Volga region, and throughout the entire Caspian lowland, the Atelian formatio[illegible] is overlain by marine Khvalynsk deposits represented by sands and peculiar "chocolate" clays characterized by banded lamination. The Khvalynsk stage deposits in the described territory, as well as in other parts of the Caspian basin, can be subdivided into smaller stratigraphic units. P. V. Fedorov [21, 22] distinguis[illegible] here the Lower Khvalynsk deposits which, in th[illegible] Lower Volga regions, form terraces having absolute elevations of 48, 35, 22-25 m (the first

are composed of loams and sands, the last of chocolate-colored clays), and the Upper Khvalynsk sandy deposits forming terraces having absolute elevations of minus 2, minus 10-12, and minus 16-17 m. Yu. M. Vasilyev considers the chocolate clays which make up the 22-25 meter Volga terrace as an independent Middle Khvalynsk horizon. The Lower Khvalynsk, marine loamy, sandy, and pebbly deposits comprise the 48-meter terrace located on the right bank of the Volga between Stalingrad and Kamyshin. They also cover the watershed terrace and all of the area in the northern part of Caspian lowland.

Thus, along the lower Volga, two alluvial-marine sedimentary complexes are clearly distinguishable: the lower, or the Lower Khazar, deposited over the plane of erosion on the marine beds of the Baku stage, and the upper, or Atelian, which, at its base, consists of brakish-water sediments. It is separated from the lower complex by a pronounced plane of erosion and distinct traces of freezing processes. Deposited above are the marine Khvalynsk formations which are either separated from the Atelian formation by traces of a hiatus, or have a gradational contact with them.

Up-stream along the Volga, the Lower Khvalynsk marine sediments are replaced by alluvial sands covering the terraces III and IV. Consequently, there are grounds to consider these (Lower Khvalynsk) deposits as the third — the uppermost alluvial stage.

The discussed complexes are also clearly well traceable beyond Stalingrad. For example, near Bukovo village (left bank of the Volga, below the city of Kamyshin), on the southern slope of the ravine, the following sequence can be observed, from the top down:

1. Soil and chocolate-colored clay eluvium; 0.8 m.

hv 2. Chocolate-colored clays, thinly-bedded, alternating with bands of yellow sands, followed by sands. The clays are deposited on a lightly eroded surface of the subjacent rocks, and in some locations, grade into them; 3 m.

at. 3. Sands, yellow, laminated and cross bedded, in some places the superjacent loess-like sandy loams are preserved; clear traces of erosion are observable on the surface of the underlying deposits; 2-3 m.

$hz_1$ 4. Brownish-grey, greenish, less frequently reddish-brown loams containing traces of freezing processes; about 1-3 m.

North of the Yeruslan River (outside the limits of the Caspian lowlands) we have observed the following sequences in the scarps of the III and IV.

Near the village of Ilovatka, on the lower reaches of the Kamyshevakha River, the following sequence is exposed in the scarp of the terrace III.

1. Soil.

kv 2. Chocolate-colored clay eluvium containing an abundance of lime nodules; 0.7 m.

at 3. Yellowish-grey sand containing thin streaks of gypsum; ochre spots are visible. The lamination of the sand is not clear; 1.5 m.

at 4. Yellow-brown porous loam containing streaks of gypsum; replaced below by poorly laminated sand containing clacic stains, mole-hills are observable; 1.5 m.

$hz_1$ 5. Heavy, brownish-fallow loam, darker in the upper sections, becomes mixed with sand toward the bottom, assumes a lighter coloration, and contains many calcareous streaks. Traces of freezing are observable in the top - pseudomorphsof glacial wedges. Toward the bottom the loam is replaced by sand.

$hz_1$ 6. Brownish-fallow loam, lighter toward the bottom, at the bottom containing yellowish-grey, occasionally light-grey sand; 1.3 m.

khz 7. Brown loam, 0.3 m.

khz 8. Dark-brown to black loam, gleyed, lumpy, unstratified, with numerous lime spots typical for loess which contains lime nodules, with ochre spots which are particularly abundant at the bottom; below, the rock becomes lighter, ochreous and sandy; 1 m.

hz 9. Greyish-brown loam, finely mottled, containing an abundance of ochreous, greenish, and black spots. At the top — a thin sand layer. The loam becomes mixed with sand at the bottom, assumes a brownish-cinnamon tint, becomes more homogeneous and gives way to bed-10 rocks. Mole-hills are visible. The top of the bed is crumpled into small folds; 1 m.

hz 10. Brownish-cinnamon, fine-grained, compacted sand; the bottom shows bands of brown loam; 1 m.

$hz_1$ 11. Yellowish-grey sand, light-grey at the bottom, with layers of brown loams and clay. Mole-hills filled with brown loam, 2 m.

Evident here is the distinct boundary between beds 2 and 3. Traces of soil formation are observable in the top of beds 4 and 8.

The following sequence appears in the ravine cutting through terrace III between the villages of Privolzh'ye and Skatovka, near the road from Kamyshin to Engel's.

1. Soil.

hv 2. Yellow-brown loam, columnar, toward the bottom, replaced by non-laminated sand; 3.6 m.

at 3. Brownish-cinnamon loam, humic, lumpy, porous, containing calcareous bands and spots, intensely calcitized; at the base of the bed the loam is dove-colored, greenish, compacted, sandy; 0.8 m.

at 4. Brownish-yellow sandy loam, dark with bluish streaks, containing round limy nodules; mole-hills are visible; 1 m.

at 5. Striated-lamellar sand, fine-grained, clayey, more homogeneous at the bottom; contains sypuchka; 2.5 m.

$hz_1$ 6. Brownish-cinnamon loam, lumpy, with an abundance of calcite streaks in the lower sections; minor frost-induced deformations are visible at the top; 0.3 m.

hz 7. Brown loam, containing pseudomycelles of lime, 0.15 m.

hz 8. Dark-brown loam, particularly dark at the top, bluish, gleyed, lumpy. The lower sections display an abundance of ochre streaks and spots. At the bottom, loam is replaced by sand; 0.8 m.

hz 9. Compacted, ochre-yellow sand, mottled, laminated, deposited in the form of a lens; 0.3 m.

$hz_1$ 10. Clayey sand, ash-grey, dark, lighter in the lower sections and less clayey; 1 m.

Here, as near Ilovatka, three horizons of deposits (beds 2, 3-5 and 6-10), separated by buried soils, can be discerned.

A good exposure of the terrace IV section (the elevation of the brow above the Volga River is about 35 m) is observable near Spasskoye village.

1. Soil.

hv 2. Yellow-brown, stratified sand, containing bands of brown loam; 3-4 m.

at 3. Brown loam with greenish bands; the top is eroded, uneven, frost-type deformations are observable, although they are minor; mole-hills are visible in the rocks; 0.5 m.

at 4. Brown loam, occasionally cinnamon, changing near the bottom to yellowish-gray, fine-grained sand, with loamy bands in the top section and homogeneous at the bottom; 6-7 m.

$hz_1$ 5. Greenish-brown loam abounding with lime spots and pockets of fresh-water mollusk shells; a cinnamon loamy bed is in the top of the section. The top of the bed is slightly eroded; 1.5 m.

$hz_1$ 6. Brownish-cinnamon loam, sandy near the bottom and gradually replaced by compacted sand, yellow-grey, finely grained; 1.5 m.

$hz_1$ 7. Yellowish-cinnamon sandy loam containing ochre spots. Small pockets of the overlying sand are observable at the top; 0.8 m.

hz 8. Heavy, lumpy, brown loam; sand filled cracks are observable, manifestations of shrinkage; 2 m.

According to Yu. A. Lavrushin [12] an outcrop of the lower part of the section which was buried under talus deposits — alluvial sands of considerable thickness — is visible near Spasskoye village. Here, as at other stations, one can observe three horizons (layers 2, 3-4, and 5-8).

Considering other available data on the structure of terraces III and IV, it is possible to conclude that the sediment sequence is fairly constant within their range; namely, visible is the lower alluvial formation — sands and shingle — overlain by silty and loamy sediments. Meadow-marshy formations are developed at the top of the formation. The top usually shows signs of frost destruction and scouring. The upper alluvial formation consists of sands overlain by loams. Buried soil is developed on its top, with occasionally observable erosion and traces of freezing. Finally, the topmost member of the terrace section is thin (not more than 5 m thick) sand and loam beds covering the terrace.

All of these horizons and their contacts are clearly visible in the overwhelming majority of the terrace sections, and they can, therefore, be traced successively down-stream along the Volga River. Moreover, the lower alluvial formation, in which the entombed remains of Khazar mammals were discovered — is traceable from the village of Spasskoye to the village of Ilovatka, and can be observed near the city of Nikolayevsk, the village of Bukovo, and further south. Near Stalingrad it is not as thick. In the top, in its roof cultivated soil layer, a Mousterian encampment has been found. In the lower Volga this formation is traceable in all exposures and was described at the beginning of this article as the Lower Khazar formation.

It is important to emphasize that along the entire course of the Volga from the lower reaches to the area of Samarskaya Luka, the Lower Khazar alluvial complex retains not only its specific features and the basic succession

of bedding, but also everywhere contains in its base ("Chernoyarian" sands) remnants of a single faunal complex of mammals — the Khazar complex. This is the lower alluvial formation, according to Ye. V. Shantser's interpretation [23], or the lower stage of alluvium, as identified by A. I. Moskvitin [16]. Almost everywhere in the top of this series one observes fossil soil, traces of erosion and cryoturbation.

The upper alluvium formation is also well traceable in the Lower Volga region. The described structure of this formation was traced by us from the villages of Vladimirovka and Yentayevka (lower Volga) up to the region of Syzran' (Spasskoye village), and, this structure is also known in the areas above Samarskaya Luka. In the opinion of A. P. Mazarovich [14] and Ye. N. Shchukina [24], terrace III, and, consequently, also the deposits of the described formation — follows the aprons of the maximum (Riss) glaciation in the Maryiyinsky district of the Volga region. Thus, the entire formation as a whole represents a periglacial formation.

In the uppermost horizon of the terrace III-IV section (near the mouth of the Yeruslan River and south of it), marine Lower Khvalynsk fauna was discovered.

Taking all these facts into account, the age of the lower alluvial formation may be determined as Lower Khazar; that of the upper — as Atelian, and that of the uppermost mantle of the terrace — as Lower Khvalynsk. It follows, then that the sediments covering the terrace, and, therefore, the terrace itself (III and IV), date back to Early Khvalynsk time. This three-member structure is determined on the basis of numerous borings drilled in terraces III-IV of the Volga.

The age of the terraces also can be established in tracing them further south.

Terrace I, above the flood plain, is well pronounced in the valley of Volga from Spasskoye village to Stalingrad, and below. On the lower reaches of the Volga, the surface of the terrace levels out and it grades into the Khvalynsk plain of the Ciscaspian, which is covered here by Upper Khvalynsk marine deposits. The same sediments are deposited upon terrace I in the lower-course area of the Malaya Uzen' River (Trans-Volga region). A similar phenomenon was discovered in the lower reaches of the Ural River by A. G. Doskach and I. P. Gerasimov [8].

Terrace II is clearly visible in the Volga valley, north of the mouth of the Yeruslan river and within the confines of the Caspian area. In the vicinity of Stalingrad it merges with the 25-m, Lower-Khvalynsk terrace. In the opinion of Yu. M. Vasil'yev [1], terrace II is of Middle Khvalynsk age.

Volga terrace III can be traced easily from the village of Privolzh'ye to Ilovatka. Here one observes a uniformity of the component sediments. This excludes the supposed possibility of the Khazar terrace III plunging in the south under the deposits of terrace II, or of the merging of the levels of these terraces, etc. Near the marginal bench of the elevated watershed in the vicinity of Ilovatka village, terrace III widens and merges with the 35-meter Early Khvalynsk Ciscaspian plain. That terrace III and the low North Ciscaspian plain from a single geomorphologic surface is evidenced by their almost identical elevation (the absolute elevation of the terrace and the plain is 30-40 m, the elevation above the Volga — about 40 m).

Terrace IV passes in the south into the correspondingly elevated (48 - 50 m), so-called, waterline marginal terrace at the northern extremity of the Ciscaspian. This terrace consists of marine, faunally characterized, Khvalynsk deposits and represents the abrasion platform of the Khvalynsk sea. P. V. Fedorov [22] considers that it reflects the maximum uplift of the basin level. We agree with Yu. A. Lavrushin [12] that Volga terraces III and IV are, stratigraphically, a single structure, since they consist of identical rocks. But geomorphologically they represent independent sedimentation surfaces associated with two development phases of the Lower Khvalynsk sea.

The Early Khvalynsk age of terraces III and IV is proven also by the fact that their level (below Saratov) does not exceed the highest level of the Early Khvalynsk basin. Its sediments, as well as the alluvium of the Volga which emptied into this sea, overlie the Khazar deposits of the said terraces.

Thus, beyond the limits of the Ciscaspian, in addition to the flood plain there exists in the Volga valley the following terraces: I - the (Late Khvalynsk) terrace above the flood plain, II - the terraces consisting of the chocolate-colored clays (Middle-Khvalynsk), III and IV - the Early Khvalynsk terraces. Analogous conclusions were made earlier by P. V. Fedorov [21, 22], M. G. Kipiani, and L. D. Kolbutov [11].

The problem is could there have been terraces older than Khazar and Baku higher than the Early Khvalynsk terrace in the Volga basin?

Whenever this or that investigator identifies Pre-Khvalynsk terraces, their age is always determined only by the position of these surfaces above the Khvalynsk (or Khazar) terrace. B. A. Mozharovsky [15], in explaining the presence of a Mindel terrace, proposed that

the level of the Baku sea rose to a height of 100 m. In thelight of present-day data, this theory appears to be totally unsubstantiated. S.V. Lyutsau[13], A.I. Moskvitin [16], and others identify Baku and Khazar terraces higher than Khvalynian terrace II. But we have already shown above that terraces III and IV ("Khazar" and "Baku") are of Lower Khvalynsk origin. In speaking of the existence of the Khazar and Baku terraces at an elevation of 60, and 90-100 m, one should assign to these terraces a large portion of the southern part of the waterline plain whose surface has absolute elevations below 100 m. However, this plain consists of typically waterline clays. Consequently, in this case, too, identification of Pre-Khvalynsk terraces is senseless.

Analysis of the known facts shows that the Khazar and Baku deposits are buried under the Khvalynsk sediments, and that there can be no Khazar or Baku terraces in the Volga valley. In Baku time a rise of the base level, caused by the transgression of the Baku sea (its maximum level was about 0 m absolute elevation, or slightly higher), led to alluvial and lacustrine-alluvial sedimentation in the Volga valley. In the Khazar age, when the sea level rose to 10-15 m absolute elevation, the Khazar deposits in the Volga valley covered the Baku beds (filling up the deep cuts). It is natural that in Early Khvalynsk time, when the sea level was elevated to 48 m absolute elevation, the Khazar beds were buried under the Khvalynsk deposits. In this case, the Khazar and Baku terraces could not have been higher than the Khvalynsk.

However, the presence of the rising steps of Pre-Khvalynsk terraces may be admitted, if one is to assume that there was an uplift of the watershed area (including the Volga regions beyond the Ciscaspian) and a subsidence in the Ciscaspian area. Then, the Khazar and Baku Volga terraces observable in the relief should exhibit a pitch towards the south and should plunge under the level of the Khvalynsk terrace at the boundary with the Ciscaspian lowland. Incidentally, such a subsidence of the Ural River valley is reported by A.G. Doskach [8]. A similar phenomenon was also noted in the Volga valley. In this case, in tracing the horizons of the Pre-Khvalynsk deposits from the lower reaches of the Volga to the mouth of the Yeruslan River and further north, we should have noticed a rise of the Baku, Lower Khazar and Atelian beds (let it be reminded that they are distinctly observable in the outcrops) and their truncation by the Khvalynsk deposits of terraces III and IV. But on the left bank of the Volga such facts were not noted (and this also applies to the Ural). Here, one observes only a gentle rise of all beds, corresponding to the elevation of the Khvalynsk terrace level. Within the limits of this terrace, both in the Ciscaspian and north of it (near the villages of Ilovatka, Skatovka, and Spasskoye), a series of successive Khazar beds is observed under the sediments deposited during the maximum transgression of the Khvalynsk sea. G.I. Goretskiy [4] describes precisely such a mode of bedding of the Khazar alluvial formations, which rise up-stream along the Volga and Kama Rivers parallel to the water line.

The Khazar and Baku terraces are buried under the Khvalynsk sediments. The rising steps of terraces can occur only in zones of intense recent upheavals, but the Syrt Trans-Volga region from the very beginning of the Quaternary always was a zone of downwarping.

Some authors, in speaking of the Baku terrace of the Volga, point out that sandy rocks not typical of the Syrt stratum are developed near the river valley. They believe them to be Baku (Mindel) alluvium. However, A.N. Mazarovich [14], in his time, and other investigators have shown that these arenaceous sediments of the "Mendel terrace" are, in the east, replaced along the strike by true Syrt deposits.

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Geological Institute of the
U.S.S.R. Academy of Sciences,
Moscow

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# METHODS

## SEPARATION OF CLAY PARTICLES BY ELECTROPHORESIS[1]

by
N. V. Logvinenko, and A. A. Lazarenko

The separation of clay fractions (<1 μ) is a very lengthy and cumbersome operation. In order to produce the few grams of this fraction required for a complex mineralogical investigation (by means of thermography, chemical and X-ray analyses), it is usually necessary to precipitate for several days, and then to evaporate clay suspensions. For large-scale operations this method is inadequate.

These difficulties can be overcome generally by utilizing the method of electrophoresis. Essentially it consists of the following. Clay particles dispersed in water from colloidal systems, and the particles carry negative electric charges on their surfaces. In the field of a direct current these particles migrate to the anode where they are discharged and deposited. This process ordinarily is not used for coarse particles of clay minerals and accessory minerals.

It is reasonable to assume that if other negatively charged colloids (humate, silica) are present in the rock, they, too, will settle on the anode.

The method of electrophoresis (often erroneously called electroosmosis) has been utilized for the technical enrichment of clays and kaolins for a long time. A diagram of the equipment used for these purposes is given in Figure 1 (1.3). A dense clay suspension is pumped from a mixer through tube d into a tank, where it is maintained in a suspended state by means of agitators c. When the electric current is switched on, the clay particles, in passing through the cathode grid b, are attracted to the anode surface a, where they settle and are removed by scraper f. The voltage required for this operation amounts to 75-100 v, the current is 100 a, and the density does not exceed 0.01 a/cm$^2$. The output of the unit is several tons of enriched product per day (approximately 1 t per 30-70 kw/h). A prerequisite condition for the industrial application of electrophoresis is the addition of alkaline electrolytes - peptizing agents (liquid glass, alkali) to impart greater stability and to increase the electrokinetic properties of the clay particles in suspension.

Electrophoretic enrichment of clays is practiced both abroad and in domestic industries.

To produce a few grams or tens of grams of fine clay particles in lithological laboratories no cumbersome installations with high current parameters are required. Depending on the available resources it is possible to utilize various operational techniques. However, to assure adequate efficiency and rapid separation of clay particles, a number of conditions must be observed. The most important of these are: 1) sufficient current density at the anode immersed in the suspension: up to 0.010-0.005 a/cm$^2$; 2) stability and sufficient density of the clay suspension (not less than 1.005-1.010); 3) optimum distance between the electrodes, 15 - 25 mm; 4) source voltage of 75-150 v.

Suspensions utilized under laboratory conditions must not contain electrolyte ions, since they are being sorbed by the clay particles and the latter may change their chemical composition or coagulate (in the presence of positively charged electrolytic particles).

In designing electrophoresis equipment the most important condition is the selection of a sufficiently powerful direct-current source, preferably with controllable parameters. VSA-5, continuous control selenium rectifiers, or type VSA-6, which may be satisfactorily controlled by LATR-1 transformer are suitable for this purpose. Use should be made of converters (motor-generators) with current of up to 5-10 a and 65-150 v. The very popular gas-filled tube rectifiers produced by the Elektrodelo Plant, usually lack sufficient power (6a, 24 v), particularly with respect to rectified voltage. This defect may be eliminated by connecting a few of these units in series. This method is also applicable for combinations with different current sources.

[1]Vydeleniye glinistykh chastits pri pomoshchi elektroforeza. pp. 100 - 103.

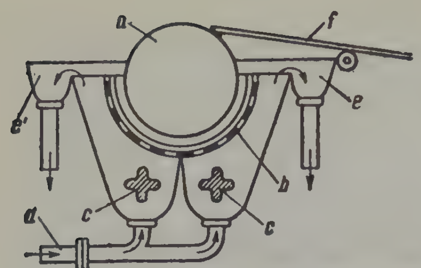


FIGURE 1. Diagram of a machine used for clay enrichment by the electrophoresis method.

(After Schwerin, 3).

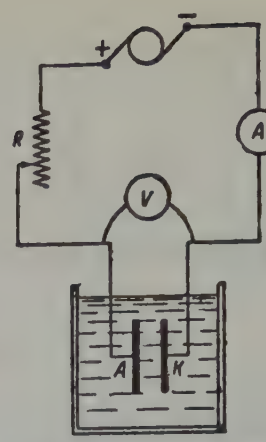


FIGURE 2. Basic diagram of the laboratory unit used for electrophoresis.

Upon selection of a suitable direct-current source, it is necessary to calculate the anode area to make sure that the current density on the surface immersed in the suspension will, under average conditions, amount to 0.01 a/cm$^2$. The density of current, evidently, depends not only on its source, but also on the distance between the electrodes, as well as on the density of the suspension. In order to increase its strength the anode can be plated by pure lead, or, even better, by an alloy of lead containing antimony (up to 15% Sb). Utilization of platinum for electrodes is impracticable in view of their large surface and correspondingly large quantities of metal required. The cathode, in the form of a copper or brass grid with 0.25-0.10 mm openings, should be approximately of the same size. The distance between the electrodes and the degree of anode immersion into the suspension must be regulated.

Depending on the size of the electrodes and the volume of the clay suspension a corresponding bath may be selected. Usually a glass crystallizer may be used for this.

To control the operating conditions it is necessary to include an ammeter and voltmeter in the circuit. It is useful also to provide for a thermometer to take the temperature of the suspension, which may rise very considerably between the electrodes because they are to close or there is a bad contact between them and the leads. The latter must be well insulated. Excessive current strength, as compared with its normal value, may be reduced by inserting a rheostat into the circuit.

The circuit diagram of a laboratory unit is shown in Figure 2.

The quantity of clay produced by electrophoresis is, as was previously stated, a function of the current source parameters, suspension density, distance between the electrodes, current density on the anode, time, and other factors. The effects of these factors can be judged from the data contained in Table 1.

The initial material for the investigation was a suspension (size of particles <5μ) of the same rock - Jurrasic hydromicaceous clay taken from the northwestern part of the Donetz basin. In all cases, an anode in the forms of a round lead plate having an over-all area of 450 cm$^2$ was inserted in a horizontal position into the suspension whose volume was about one liter.

Table 1 shows that the density of current during the operation was, on the whole, insignificant: 0.0025-0.0050 a/cm$^2$, mainly due to the relatively large surface of the anode. This indicates that the method of clay electrophoresis isoperative even under such unfavorable conditions.

Generally, however, because of low suspension density and the absence of electrolytic additions, in operations designed for special purposes and conducted under laboratory conditions, the deposition of clay particles per identical unit time and unit anode area is smaller than in the industrial enrichment processes.

Greater efficiency can be achieved by increasing the current-source parameters and augmenting the density of the initially prepared suspension. For example, in the Petrography Department Laboratory of Khar'kov University, a 180-v and 13-a converter serves as the source of current. The strength of the current in the circuit usually amounts to 2.5 - 5 a. The area of the anode lead cover is 37 cm$^2$. With a density of suspension of 1.008-1.011, the output of clay

Table 1

Effect of different conditions in the electrophoresis process.

| Variables | Voltage | Current strength in amperes | Distance between the electrodes, mm | Density of suspension | Duration of operation, min. | Current density at anode, a/cm² | Quantity of separated clay (dry), g | Remarks |
|---|---|---|---|---|---|---|---|---|
| Voltage (and strength) of current | 55 | 0,25—0,35 | 20 | 1,010 | 6 | 0,0006—0,0008 | 0,80 | Coagulation of suspension during operation |
| | 75 | 0,60—0,80 | 20 | 1,010 | 6 | 0,0013—0,0018 | 1,08 | |
| | 100 | 1,00—1,25 | 20 | 1,010 | 6 | 0,0022—0,0028 | 1,49 | |
| | 125 | 1,30—1,80 | 20 | 1,010 | 6 | 0,0029—0,0040 | 1,98 | |
| | 150 | 1,50—2,50 | 20 | 1,010 | 6 | 0,0033—0,0056 | 5,67 | |
| Density of suspension | 100 | 0,60—0,80 | 20 | 1,005 | 10 | 0,0013—0,0018 | 0,97 | Noticeable coagulation of suspension |
| | 100 | 0,85—1,10 | 20 | 1,010 | 10 | 0,0019—0,0024 | 2,15 | |
| | 100 | 0,90—1,20 | 20 | 1,015 | 10 | 0,0020—0,0027 | 2,35 | |
| | 100 | 1,00—2,85 | 20 | 1,020 | 10 | 0,0022—0,0063 | 2,87 | |
| | 100 | 1,00—2,90 | 20 | 1,030 | 10 | 0,0022—0,0065 | 4,41 | |
| | 100 | 1,00—5,40 | 20 | 1,050 | 10 | 0,0022—0,0120 | 5,11 | |
| Distance between the electrodes | 100 | 3,00—10,00 | 5 | 1,005 | 4 | 0,0067—0,0222 | 1,29 | Very considerable heating of suspension - termination of operations |
| | 100 | 1,90—7,00 | 10 | 1,005 | 6 | 0,0042—0,0156 | 1,66 | Considerable heating of suspension |
| | 100 | 1,25—1,50 | 15 | 1,005 | 7 | 0,0028—0,0033 | 2,10 | |
| | 100 | 1,30—1,15 | 20 | 1,005 | 7 | 0,0029—0,0026 | 2,13 | |
| | 100 | 0,80—0,50 | 25 | 1,005 | 7 | 0,0018—0,0011 | 1,99 | |
| | 100 | 0,70—0,50 | 30 | 1,005 | 7 | 0,0016—0,0011 | 1,86 | |
| Times | 100 | 1,00—1,25 | 20 | 1,010 | 5 | 0,0022—0,0028 | 1,25 | Noticeable coagulation of suspension |
| | 100 | 0,85—1,10 | 20 | 1,010 | 10 | 0,0019—0,0024 | 2,15 | |
| | 100 | 1,00—2,00 | 20 | 1,010 | 15 | 0,0022—0,0044 | 2,50 | |
| | 100 | 1,00—2,10 | 20 | 1,010 | 20 | 0,0022—0,0047 | 2,85 | |

NOTE: Comma represents decimal point.

at the anode amounts to 20-30 g per 6-8 min of work.

Efforts should be made to assure the greatest possible degree of dispersion and purity of the clay particles deposited at the anode by systematic microscopic checks. The data obtained indicate that sufficiently pure clay is precipitated at the anode from the suspension with particles less than 5μ in diameter and there are almost no fragmental grains of quartz and other minerals.

The moisture of the separated clay usually exceeds 50% (amounting to 65-80%). It is in inverse relation to the magnitude of voltage and current strength, as well as to suspension density.

General Sequence of Operation. A stable suspension in a volume of 1-2 liters, (depending on the size of the apparatus), is prepared from a corresponding batch of clay rock and distilled water. One hour and 20 minutes later the top 10 cm of suspension containing particles measuring less than 5μ are decanted and used for electrophoresis. The density of the suspension measured by an areometer

must not be less than 0.005-0.010. The suspension is poured into a bath in which the electrodes have been previously installed. The optimum distance between them should be 15-25 mm. After a few minutes of work the anode is withdrawn from the suspension and clay is removed from its surface. A few smears are made on the object glass for microscopic verification of the purity of the deposits. If the amount of clay produced is insufficient the process may be repeated, with the current increased by putting the electrodes closer together. After the work is finished, the electrodes should be thoroughly washed and rinsed in distilled water.

A set of different sizes of electrodes should be available for each electrophoresis apparatus. In varying the different procedural parameters, it is possible in each particular case to create the most favorable conditions for deposition of clay fractions.

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Khar'kov State University

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# THE 1961 LAUREATES OF THE LENIN PRIZES[1]

by

**N. M. Strakhov — Originator of the Theory of Lithogenesis**

The appearance of N. M. Strakhov's monograph, The Principles of the Theory of Lithogenesis, for which the author was awarded the well-deserved, highest prize — the Lenin Prize —, came as no surprise to geologists. This event was well argued by Nikolai Mikhaylovich's numerous previous works and his entire scientific activity. Beginning in 1937, N. M. Strakhov, with the natural talent and concentration so characteristic of him, focused all of his efforts on the elaboration of the theory of the sedimentary process, believing that the method of comparative lithologic analysis would lead him more directly to his goal. N. M. Strakhov's monograph is proof that he selected the correct path. In terms of its value to the science of lithology, there is no work equal to his Principles of the Theory of Lithogenesis, either in this country, or abroad.

The first volume of the monograph contains the doctrine on the types of lithogenesis: glacial, humid, arid, and effusive-sedimentary. A detailed scheme is given for the humid-type of lithogenesis, a thorough analysis is made of the processes occurring in catchment areas, of the mobility of various elements in the weathered mantle, the laws of mechanical and chemical denudation, the types of fluvial transportation of materials, the origin of sediments in basins, as well as of the diagenetic and epigenetic changes in the process of transformation of sediments into rocks.

Having discussed the stages of humid-type lithogenesis, the author proceeds to the description of humid formations as related to the paragenesis of sedimentary rocks, and in doing so, bases his discussion on a clearly-defined genetic concept of the process. He establishes the decisive role played by topography and structural environment in the formation of humid rocks and their associations, and defines the peculiarities of formations developed on the platforms and in geosynclines at different stages of their development. Against a background of minutely described humid lithogenesis, the main features of the remaining three types of rock formation — glacial, arid, and effusive-sedimentary — become more graphically apparent. In discussing the distribution of the climatic types of lithogenesis on the Earth's surface in Post-Proterozoic time, the author develops a pattern of past climatic zonality.

N. M. Strakhov conclusively demonstrates the advantages of lithologic indicators over the paleontological for the reconstruction of climate. These chapters are illustrated with very interesting paleoclimatic maps. Since the maps are based on the distribution of such indicator-rocks as bauxites, iron, and manganese ores, the crust of weathering, coals, rock and potash salts, they also simultaneously serve as patterns of zonal distribution for commercial minerals throughout the entire period of the Earth's geologic history. The analysis ofpaleoclimatic maps leads the author to a conclusion concerning the repeated migrations of all climatic zones throughout the Earth's history, associated with the changing positions of its axis of rotation relative to the mantle.

The second volume of the monograph is devoted to an analysis of the regularities governing the composition and distribution of humid deposits. Considered attention is paid thereby to the conditions and the mechanism of formation of high aluminum, iron, manganese, phosphorus, $CaCO_3$, $MgCO_3$, and $SiO_2$ concentrations, as well as to polarity zones in the distribution of rare and dispersed elements. A step-by-step examination is made in this volume of the granulometric composition of silty-argillaceous rocks of various types of facies formed under varying climatic and structural environments; delineated are the distribution zones of components the complex forms of migration: iron, manganese, phosphorus, and minor elements. Sedimentary ore deposits are subdivided, for the first time in the literature, into three facies-genetic groups.

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[1] Laureaty Leninskikh Premiy 1961. N. M. Strakhov — Osnovopolozhnik Teorii Litogeneza. pp. 104 - 105.

identified for each ore component, is its facies profile, and the formative mechanism of ore concentrations. The emplacement of ores in synchronous tectonic structures and metalliferous formations is analyzed, and the evolution of ore deposition in the history of the Earth discussed.

The last chapters of the second volume are restricted to a detailed examination of the diagenesis of subaqueous deposits, the basic premises for which were formulated in 1953. In the new monograph, the author delved deeper into the substance of minerogenetic processes and the redistribution of matter in diagenesis. He also outlined the development peculiarities of diagenetic processes in basins of varying physical and geographic characteristics.

This year will see the publication of the third volume of his Principles of the Theory of Lithogenesis devoted to arid lithogenesis. Discussed here exhaustively are the particulars of sedimentation and ore-formation in an arid environment, the basic features of modern halogenesis, as well as halogenetic evolution in Post Algonquian time.

Manifest in the third volume, just as in the preceding two, is N. M. Strakhov's persistent attempt to disclose the physiochemical essence of the processes involving the formation of sedimentary rocks.

At the present time N. M. Strakhov directs his own efforts and those of his associates toward the study of the geochemistry of sedimentary rocks. He has advanced the problems of the facies-genetic relations between the scattered concentrations of elements and their ore accumulations in humid zones. Solution of this problem will make it possible to understand the distribution and accumulation mechanism of elements, i. e., brings us closer to the development of the theory of geochemical processes, and help us to provide better substantiation in diagnosing ore occurrences.

## REVIEWS AND DISCUSSIONS

# THE PROBLEM OF THE NOMENCLATURE OF EFFUSIVE ROCKS[1]

by
T. Ya. Goncharova

In Ye. K. Ustiyev's article The Problem of the Nomenclature of Effusive Rocks, published in Izvestiya Akademii nauk SSSR, seriya geologicheskaya, No. 11, 1959, an important problem was raised concerning the unfortunate situation concerning the classification of effusive rocks which is causing a great deal of concern among geologists engaged in the study of sedimentary-volcanic complexes and the related ore deposits. The poorly developed nomenclature of effusive rocks and their pyroclastic varieties considerably hampers the detailed mapping of mining districts and complicates the study of deposits enclosed in extrusive rocks.

Ye. P. Ustinov's article and the critical reviews published by S. N. Ivanov and V. I. Lebedinskiy in the Izvestiya AN SSSR, seriya geologicheskaya, No. 7, 1960, discuss the advisability of two parallel nomenclature systems for fresh cenotypal and altered paleotypal effusive and subvolcanic rocks.

Ye. K. Ustiyev proposed that the two parallel nomenclatures for effusive rocks be abandoned and a single nomenclature scale corresponding to the cenotypal series be adopted. Rock variations in his opinion, could be indicated by adding the word "paleotypal" or, by the words "altered" or "decomposed" which are preferred in the Russian language and which more accurately reflect their meaning.

S. N. Ivanov and V. I. Lebedinsky strongly object to Ye. K. Ustinov's proposals and defend the necessity of maintaining a double nomenclature for effusive rocks.

The above papers, it seems to us, outline two different trends in the specification of classification principles: principal emphasis is on the primary properties of rocks, or, conversely, the secondary properties of effusives acquired as a result of subsequent metamorphism.

We believe that both property of extrusive rocks are equally important.

1. The primary character of effusive rocks, which can be discerned in the altered varieties only after thorough analysis of their optical properties and chemical composition, makes it possible to reconstruct the conditions under which the rock was formed and to relate it to a definite magma. Only the primary properties of a rock can furnish the correct representation of the geologic environment in which it was formed, information of crucial importance for further geologic and metallogenic generalizations

2. Of no less importance are the secondary properties of effusive rocks acquired in the process of aging, and by structural and metamorphic transformations. The present state of a rock certainly reflects its geologic history, since the rocks, as was aptly stated by V. I. Lebedinskiy, are the monuments of geological processes.

Thus, both of these elements must be reflected in the names of effusive and subvolcanic rocks.

In our opinion, composition-wise more correct and more convenient to use is that classification of extrusive rocks in which the names of both, the fresh and the altered, lavas of one genetic series have the same roots. We, therefore, propose to preserve the roots of the nomenclature series embracing the cenotypal effusives for all of their altered analogs. To express the subsequent transformations experienced by the rocks, it is recommended to append characteristic prefixes (or suffixes).

For example, in taking the cenotypal family of effusives given in Ye. K. Ustiyev's paper as a basis, it is possible, in accordance with M. A. Usov's views concerning the existence of three constitutional phases of effusive rocks, to isolate three petrographic series.

[1]K voprosy o nomenklature effuzivnykh gornykh porod. pp. 106 - 107.

| Cenotypal | Paleotypal | Greenstone (metamorphic) |
|---|---|---|
| 1. Liparites | 1. Paleoliparites | 1. Metaliparites |
| 2. Sodium liparites | 2. Sodium paleoliparites | 2. Sodium metaliparites |
| 3. Liparite-dacites | 3. Paleoliparite-dacites | 3. Metaliparite-dacites |
| 4. Dacites, etc. | 4. Paleodacites | 4. Metadacites |

We do not aspire to have precisely this classification scheme introduced for effusive rocks — this is merely an example of one of the possible variants. It is quite possible that other more appropriate prefixes and suffices ("apo" instead of "paleo", suffix "oil" instead of prefix "meta") may be found. This matter should become the subject of further discussions. However, we believe that the principle used as the basis of the proposed scheme, is the most suitable of all.

We are firmly convinced that the classification of paleotypal and metamorphized effusives should be revised. The long, and often unsuitable, designations of effusive rocks must be replaced by new terms, which should, of necessity, retain the roots of the initial cenotypal analogs. The presence of roots pertaining to cenotypal effusives in the names of the altered varieties emphasizes their consanguinity, pertinence to a single genetic series, and considerably facilitates the development of a nomenclature scheme. Along with further elaboration and detailed development of the classification for cenotypal effusive series, the nomenclatureof altered rocks will be correspondingly improved. All the identified varieties of cenotypal effusives, including those of intermediate composition, which as yet have no analogs in the petrographic nomenclature for altered series, will find their place in the proposed classification scheme. The new terminology can be adapted easily to pyroclastic rocks.

Despite the many years of study on the old, predominently Paleozoic, strongly altered volcanic formations surrounding the chalcopyritic deposits in the Caucasus, Altay, and partially in the Urals, we cannot share S. N. Ivanov's apprehensions concerning the great confusion which will arise if, in following Ye. K. Ustiyev's suggestion, the paleotypal designations of rocks are replaced by cenotypal terms on the geologic maps of the regions where altered effusives predominate. On the contrary, we feel that the maps can only gain thereby and will be of greater value. This, of course, provided this replacement is made not on the basis of "the discretion of individual map authors" (S. N. Ivanov), but after a detailed and considered petrographic study of the effusives. A reflection of the characteristic alteration peculiarities in the description of rocks is also a prerequisite condition.

The identification of the primary aspect of altered effusives on the basis of relict mineralogical composition and texture, and the reconstruction of their geologic life, represent one of the main tasks in the petrography of volcanic complexes.

Thus, the suggestions briefly outlined in this article should be considered as a further expansion and development of Ye. K. Ustiyev's ideas.

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# THE NOMENCLATURE OF EFFUSIVE ROCKS[1]

by
I. M. Speranskaya

The syposium on the classification, nomenclature, and terminology of volcanic rocks constituted an important part of the First All-Union Volcanological Conference. However, the overwhelming majority of papers dealing with this subject was devoted to pyroclastic rocks, whose classification is still very poorly developed. Only one author — Ye. K. Ustiyev — paid serious attention to the substantial defects in the nomenclature and the classification principles of paleovolcanic extrusive rocks. Later on, he published a special article restricted to the classification of effusives (Izvestiya AN SSSR, seriya geologicheskaya, No. 11, 1959), in which he again stressed the need to regulate the nomenclature and suggested that the nomenclature referring to "paleotypal" lavas be discarded.

The development of more precise specifications for the classification principles and the existing nomenclature of effusive rocks is long

[1] O nomenklature effuzivnykh gornykh porod. pp. 107 – 108.

since overdue. At the Volcanological Conference, attended by the leading petrographers-volcanologists of the Union, the speakers often used a very diversified nomenclature for effusives which was not always reconcilable with any definite principle of classification. This situation has a bad effect on the geological surveys carried out by field geologists in different volcanic regions of our country.

For purposes of relatively small-scale geologic mapping, an important segment of field geologic operations, the problem of a coordinated nomenclature for effusive rocks is, at present, of particular importance. This is due to the fact that, in various old and recent volcanic regions throughout the USSR, a great deal of factual material on the geology and petrography of volcanic formations has been assembled and still continues to accumulate. One of the methods by means of which all this material could be generalized is the preparation of the State geologic maps (on various scales) for the entire territory of the Union. To facilitate the future comparisons of volcanism in various regions, it is advisable that a single nomenclature relative to the effusive rocks should be used in the legends of these maps. Considering the very brief explanatory notes accompanying the maps, the terminology problems are particularly important.

During the many years devoted to the study of Mesozoic effusives in the Okhotsk-Chaun volcanic zone in Northeast Asia, and to the editing of geologic maps covering this territory, I was repeatedly confronted with the great confusion prevailing in the terminology of effusive rocks. This creates considerable problems with respect to mapping, and sometimes it is impossible to make conclusive comparison of the available materials with the published data.

At the same time, it should be emphasized that a considerable proportion of geologists working on Northeast Asia utilize a single "cenotypal" classification of effusives. At the Interdepartmental Stratigraphic Conference (Magadan, 1957), where problems of the stratigraphic differentiation of eruptive formations were also discussed, the authors of many reports used "neo" volcanic nomenclature. The widespread use of "cenotypal" nomenclature for effusive rocks by the geologists concerned with the Northeast is not accidental. This is primarily attributable to the peculiarities of the Mesozoic stages in the geologic-tectonic history of Northeast Asia, where the most powerful manifestations of volcanism are related to Upper Mesozoic and Cenozoic tectonics. In the Okhotsk-Chaun volcanic zone, which used to serve as the main arena for powerful Cretaceous volcanism, a major tectonic reconstruction must have, apparently, occurred in the Pre-Devonian time. Considerable tectonic movements are found also on the boundary between the Cretaceous and Paleogene.

Thus, Cretaceous volcanism developed under conditions of considerable tectonic mobility, which was particularly typical during its early stages. The volcanic rocks are, therefore, altered in varying degrees. Although a general strengthening of the "paleotypal" characteristics was established as we progress from younger to older rocks, the degree of secondary alteration, even in the synchronous effusives, was found to be extremely uneven. Among the relatively cenotypal lavas there sometimes appear considerable zones of paleotypal rocks. Moreover, in the neighboring outcrops, or even in the very same ones, it is possible to observe extrusive rocks forming one and the same cover, but sharply differing in the degree of secondary alterations. Here one may observe the entire range of transitions from the fresh to strongly altered rocks with identical composition. Under these circumstances, the determination of the degree of "paleotypal" development (and, consequently, also the use of one term or another) becomes, to a considerable extent, a matter of subjective judgement. In connection with the unavoidable subjectivity of determinations, different nomenclatures are frequently used to designate effusive rocks of the same formation in different regions. This makes the correlation of stratigraphic sections exceedingly difficult.

Only the utilization of a single "neo"-volcanic nomenclature would permit an objective characteristic to be given to rocks typical of volcanic complexes, and to single out areas having special types and different degree of secondary alterations, without isolating these rocks from the single complex through the application of varying designations. Exclusive utilization of "cenotypal" classification also may have a favorable effect on the methods used in the investigations of effusives.

In studying, for example, a stratum of relatively cenotypal andesite lavas, the investigator, upon finding a zone of altered rocks, will no longer be able to simply call them "porphyrites". Experience shows that the following cases are not atypical in geologic mapping: when "formations of porphyrites" are identified without sufficient analysis of the altered rocks, while, in reality, they have no independent stratigraphic importance. In making use of the "cenotypal" classification, the geologist necessarily will have to compare the altered rock with the same type of effusive rocks of cenotypal aspect, to identify the nature of secondary alterations, and only then draw a conclusion as to the relationship between the cenotypal and paleotypal representatives.

Thus, in describing the Mesozoic volcanic formations in Northeast Asia, one should refrain from using a dual nomenclature for the effusive rocks, especially, because this territory is a component of the enormous Pacific volcanic belt, for a large section of which (The American littoral, the Japanese Islands, and China) geologists use a uniform "cenotypal" nomenclature for effusive rocks.

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# MAIN RESULTS OF THE DISCUSSION ON THE NOMENCLATURE OF EFFUSIVE ROCKS

by
Ye. K. Ustiyev

Sometime ago I made a report [15] and published a paper [14] proposing a change in the nomenclature of effusive rocks. The main objective of this long overdue reform is the elimination of a dual set of designations for effusive rocks differing only in geologic age or degree of post-volcanic alteration. The following quotation sums up the basic conclusions contained in these papers: "The 'nomenclatural' subdivision of extrusive rocks into 'young' and 'old', or 'paleotypal' and 'cenotypal', is historically inherited from European, (including the Soviet) petrographers from the early development stages of geology and petrography in Central Europe. This hangover of a long past stage, which even in the last century had an inhibitive effect on the development of petrographic nomenclature, has, in our time, become a crying anachronism."

A general liquidation of the entire nomenclature table relating to the "paleotypal" lavas will contribute to the removal from petrography of a number of superfluous, logically unsubstantiated, designations, and will lead to greater uniformity and harmony in the world's petrographic terminology.

As one might have expected, the suggested regulation of the nomenclature for effusive rocks attracted the attention of many petrographers and gave rise to lively discussion. At present, it has become definitely possible to sum up the published remarks.

T. V. Dianova [2] writes that "proposal made by Ye. K. Ustiyev is timely and fundamentally correct". N. D. Zlenko and M. A. Tarkhova [4] believe that the "article by Ye. K. Ustiyev is very timely, and the positions stated in it are definitely progressive". T. Ya. Goncharova [1] and I. M. Speranskaya [10] also insist on the necessity of correcting the "essential defects in the nomenclature and classification principles" of paleovolcanic effusives and their pyroclastic varieties. Both authors feel that these shortcomings are reflected not only in the present-day state of our theoretical petrography, but also "strongly hamper the mapping of mining districts and complicate the study of the deposits in the volcanic rocks" (T. Ya. Goncharova).

Amost all of these authors not only declare themselves in favor of the proposed uniform nomenclature for effusive rocks, but further develop it in specifying certain details of the set of designations for altered lavas and the comagmatic extrusive rocks of veined nature. Such initiative should be welcomed. It attests not only to the vitality of the idea, but also to the inherent promise of progress, both in the theoretical and applied (geologic mapping) aspects of petrography.

The essence of the conclusions arrived at by all five of the authors referred to above may be summarized in the following four [sic] points: 1) a fundamentally single nomenclature should be adopted for the effusives of any age or stage of alteration; 2) as a basis for further improvement of the nomenclature for altered effusives, it is necessary to make use of the nomenclature for the cenotypal family of lavas distinguishable by particular richness and flexibility due to the historical conditions of petrographic development; 3) the designations of effusive rocks must be derived by means of adjectives, suffixes, and prefixes, retaining the root which indicates a corresponding cenotypal lava, for example: basalt — altered basalt (paleobasalt) — metamorphozed basalt (metabasalt) — deeply metamorphozed basic effusive rock (metabasite); 4) the nomenclature of effusive rocks must be made to correspond

[1] Osnovnyye itogi o nomenklature effuzivov. pp. 109 - 114.

with the parallel series of intrusive and vein rocks.

It is easy to perceive the harmony in spirit and form of these conclusions with the proposals which were used as their basis. Quite reasonable is the suggestion that the details of this problem be considered by a special nomenclature commission. It is obvious that the recommendations of such a commission must be decisive for the development of a corresponding division in our petrography.

At the same time it would have been wrong to believe that the discussed reform in the nomenclature of effusive rocks would meet with opposition. It is a well-known fact that even the most modest progress in science is always confronted with obstacles and cannot be achieved without overcoming the "traditions" it contradicts.

Two of the published reviews — one by V.I. Lebedinskiy [6], the other by S.N. Ivanov [5] — reject the idea of a uniform nomenclature for effusives. Many of the arguments advanced have already been refuted by T.V. Dianova, N.D. Zlenko, M.A. Trakhova, T.Ya. Goncharova, and I.M. Speranskaya. Nevertheless, an additional analysis of the objection against the reform may prove useful.

I.V. Lebedinskiy's criticism is based on a perfectly correct idea that it is important to maintain "a geologic approach to effusive rocks" and that "anti-historical concepts" are inadmissible in petrography. However, lack of consistency in the discussion of various aspects of the problem has brought him to erroneous deductions drawn from a reasonable premise.

In dealing with the first question he writes: "Ye.K. Ustiyev for some reason forgets about M.A. Usov who has made a special study of the existence of conditions of extrusive rocks after their formation depending on the peculiarities of the geologic environment, and has developed, on this basis, their classification and nomenclature... M.A. Usov has identified three families of rocks — the primary phase (cenotypal), the diagenetized (paleotypal) and the greenstones...".

This approach is based on two errors. First of all, it is impossible to consider seriously that the "geologic approach" to the nomenclature of effusive rocks will be destroyed if "porphyrite" is to be called "altered (paleotypal) andesite", and "melaphyre" be referred to as "altered (paleotypal) basalt". At the same time, it is clear that the very opportunity of identifying in some ancient volcanic formation, instead of the rather vague "porphyrites", at least a more specific formation of paleotypal andesite-basalt, or trachy-andesite (for which there is no designation in the "orthodox" nomenclature defended by V.I. Lebedinskiy), is already an advantage, since this saves the petrographer from the danger of distorting its geologic and magmatic history.

In addition, the assumption that "Ye.K. Ustiyev has forgotten about M.A. Usov" is wrong. In a very similar way, V.I. Lebedinskiy seems to have "forgotten" the proposal to divide into diagenetized "phases" not only effusive, but also intrusive, rocks.

As is well known, the classification of igneous rocks developed by M.A. Usov [12, 13] on the basis of this principle can be represented in the form of the table.

I am not aware, however, of any published work in which V.I. Lebedinskiy would have designated fresh granites as charnockites, granodiorites as kavkazites, and diorites as andendiorites; just as he fails to see the necessity of special designations even for the totally altered (uralitized, scapolitized, chloritized, etc.) gabbro, diorite and other rocks of intrusive origin. Thus, he obviously refuses to recognize a dual nomenclature for intrusive rocks, but cannot do without a dual nomenclature where effusive rocks are concerned! It may be clearly deduced therefrom that the matter in question is not the "forgetfulness" of this or that petrographer, but rather the consistency with which he develops his views on the nature of matter. It should be said that any strict classification of natural phenomena, first of all, requires uniformity of measurement units, or, at least, of the principles on which this classification system is based. However, it is precisely this uniformity in approach to the basic principles of classification and systematization of igneous rocks that V.I. Lebedinskiy, regretfully, lacks.

The opinion regarding the "anti-historic character" of a single nomenclature for effusive rocks easily can be refuted with the aid of V.I. Lebedinskiy's own materials. In the very recently examined [7] example of "spilitic-keratophyre" effusives of the Crimea, studied long ago by F.Yu. Levinson-Lessing [8], he described a lava stream, whose top is composed of andesites, the central part - of hydrothermally altered andesites (which, of course, are called by the author "porphyrites"), and the bottom - of almost totally reworked andesites (referred to as "keratophyres"). Thus, one and the same lava, from one and the same sheet, but considerably altered by post-volcanic processes, was given three different designations usually associated by all supporters of dual nomenclature with different historical diagenetic phases and remote families of rocks.

If such ideas of a natural process are to

| Primary phases | | Diagenetized phase | | Greenstone phase | |
|---|---|---|---|---|---|
| Effusives | Intrusives | Effusives | Intrusives | Effusives | Intrusives |
| Liparite | Charnockite | Quartz-porphyry | Granite (anoterite) | Quartz-keratophyre | – |
| Dacite | Kavkazite | Quartz-porphyry | Granodiorite (opdalite) | Quartz-keratophyre | – |
| Andesite, etc. | Andendiorite, etc. | Porphyrite, etc. | Diorite, etc. | Diabase, etc. | – |

be considered "historical", what then should one regard as "anti-historical"? It is perfectly clear, that in calling the cap lava - andesite, that of the middle section - chloritized andesite, and the bottom lava-silicified and albitized andesite, we would have related the description to the geologic environment, and would have, thereby, made ithistorical in the precise meaning of the word.

It is clear, that in systematizing effusives, one should take into account the characteristics of their composition as related to the post-volcanic alterations, but it is no less clear that in relating the system only to these features, we are distorting the history of a natural phenomenon. A heart, even if affected by sclerosis, is still called a heart so long as it does not turn to ashes. Consequently, only the total disappearance of the initial characteristics justifies a change in designation. In the given case, it is obvious that only a transformation of the effusive into a metamorphic rock may constitute such a boundary. The problem thus is reduced to determining the place and character of this boundary, which, evidently, is located outside of the area to which the terms "porphyry" and "porphyrite" apply.

Now, may we make a last remark with respect to V.I. Lebedinskiy's criticism. In relating the necessity of preserving a dual nomenclature to M.A. Usov's views relative to the "diagenetized" and "greenstone phases" of effusives, he writes that "this achievement of Soviet geologic thought cannot be simply written off". A reference has already been made above to the necessity of further study and consideration of the post-volcanic transformations of effusives of which M.A. Usov has written in his work (even though his views require substantial revision, as was reasonably noted by V.I. Lebedinskiy himself). As to the dual nomenclature, which, incidentally, was created long ago in Germany, one could attribute it to Soviet geologists only in consequence of an obvious error.

The next article – by S.N. Ivanov – is noteworthy for its even greater "orthodoxy". The author stands pat on the positions of descriptive petrography. He considers as totally unacceptable not only the proposed introduction of a single nomenclature, but he also rejects the requirement advocated by V.I. Lebedinskiy for a "geologic approach to effusive rocks". S.N. Ivanov's polemic article first of all decries the proposed introduction of a single set of designations for effusive rocks as an anachronism and a step backward. In order to appreciate the paradoxical nature of such a view, one should recall that it is based on the principles formulated by F. Zirkel [16] exactly 95 years ago! It is true that S.N. Ivanov makes no mention of F. Zirkel, G. Rosenbusch, and other petrographers who laid the foundations for a nomenclatural differentiation of fresh and altered effusives. He refers only to A.N. Zavaritskiy's proposal for a modernized system of designations for effusive rocks consisting in appending the name of a corresponding paleotypal variety to its cenotypal equivalent ("liparitic porphyry", "andesitic porphyrite", etc.). No doubt, however, this suggestion is only a compromise solution, which stressed a search for a way out of the nomenclature crisis (for there would have otherwise been no need to advance this suggestion). I have already written that this "effort to achieve the greatest possible etymological approximation of the two nomenclature systems points out the imminent necessity for their total merger (or, more precisely, for the elimination of one of them)".

It should be stressed here that A.N. Zavaritskiy himself, regardless of the compromise solution he advocated, has clearly expressed his own attitude toward the dual nomenclature for effusives. In discussing the historical reasons for its emergence, he writes [3]: "Initially, in the development of the science of geology... it was assumed that at different periods of the Earth's history... the conditions of rock formation were sharply different... Thus, at the initial development stage of petrography the geologic age was the basis for classification. But later, the Paleozoic and more recent (Tertiary and Post-Tertiary) effusive rocks were divided into two different genetic groups, regardless of their obvious affinity, and this differentiation came to an expression also in the petrographic terminology... The duality of designations... is to a certain extent a left-over from the past and essentially abandoned concepts (underscored by the author). This is the reason that we do not find this duality in the groups of rocks

identified recently, when these ideas have already become obsolete... The chief objective difference between the Paleozoic effusive rocks and the corresponding younger rocks is the degree of alteration resulting from the more recent secondary processes. If this characteristic is to be given a classification significance, then the dual nomenclature of rocks may be justified, but it should be applied depending on the general aspect of the rock, on the degree of deuteric alterations, and not on age".

Hence, the attitude of A.N. Zaritskiy, to whom S.N. Ivanov refers in support of his own views, is perfectly clear. A dual nomenclature is a left-over from an earlier stage of the development of petrography and may be partly justified only if totally dissociated from the age principle, provided the modernized designations recommended by him are duly introduced. From here there remains only one logical step to total rejection of dual nomenclature. Only a biased attitude could induce one to deny the fact that the term "altered (or paleotypal) liparite" better conveys an idea of the basic properties of this effusive than does the less definite and ambiguous[2] designation: "liparitic porphyry".

Nonetheless, S.N. Ivanov continues to insist that a rejection of dual nomenclature is a dangerous simplification, which will unavoidably lead petrography to impoverishment and regression. The existence of the science without the terms of "porphyry" and "porphyrite" appears impossible to him. He even considers enriching it by new designations: quartzephyre, apoquartzephyre, etc.

One should, in the first place, re-emphasize the fact that a single nomenclature is not poorer, but richer in terminology than a nomenclature system corresponding to sepcial designations for altered effusive rocks. Furthermore, rejection of certain obsolete concepts is a prerequisite for any progress. The Russian orthography in discarding the letters ъ, ѣ, і, ѳ, and ѵ has formally become "poorer" through loss of five letters, but this "simplification" turned out to be an indispensable element in the development of our language. Of course, far from all were satisfied with the reform. In this case too, there appeared to be some defenders of the old traditions, who believed that without the letter ѣ, the Russian people would never survive. Prof. A.I. Tomson [11] wrote in this connection: "I have already shown that the elimination of the letters ъ, ѣ, і, ѳ, and ѵ will directly complicate and disorganize the harmonious system of Russian declensions and conjugations. With the abolishment of these letters the difference would disappear between such words as "сведеніе" and "свѣдѣніе", "ѣсть" and "есть", "міръ" and "миръ", etc. These changes in orthography threaten to dislocate the established mechanism of thought and weaken mental activity among the literate". A similar situation engendered in both professors a similar reaction!

S.N. Ivanov's article shows, however, that this opposition is directed not only against the single nomenclature, but also against the very principle serving as the basis for systematization and classification of effusive rocks. S.N. Ivanov in this case holds fast to the rule whose origin may be traced back to the epoch when microscopic physiography was the leading science. He writes: "It seems to me that preference should be given to those designations of rocks which are determined not on the basis of some abstract concept but by actually existing and unquestioned petrographic characteristics observable in every fragment or, at least, in every natural bedrock outcrop".

This quotation explains the true reason for the difference in opinions. It is important to emphasize right away and most decisively that this approach to rocks, which in its time was known as "fragment petrography", has, in our day become largely obsolescent. The rapid development of geology and petrography has upset many traditional ideas of the past era. It has, first of all, brought to the foreground genetic problems of effusive rocks which turned out to be far more complicated than they appeared to petrographer-microscopists. The ever emerging new proofs of the major role played by the phenomena of heterogenesis and convergence of features seriously complicate the task of rock determination "in fragment" and even in "bedrock outcrop". Not so isolated are the cases when a good knowledge of the geologic circumstances in the entire investigated area is required for a correct determination of the origin, higtory, and the name of a rock "fragment". Without this knowledge it is difficult, and impossible at times, to distinguish granite from granitized sedimentary rock, altered basalt from altered liparite, ignimbrite from lava, and so on. Even so distinguished a scientist as Ye.S. Fedorov has made a major error when, guided by principles of "fragment petrography", he described the metamorphic rocks, "kelabekite" and "drusite", as extrusive.

Thus, a geologic-genetic approach to rocks

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[2]Let it be recalled that the word porphyros originally means "red", and porphyros lithos means red stone. Hence, such word formations as, for example, "greenstone porphyrite", "grey porphyrite", "black porphyrite" and so on, appear to be obviously unreasonable. This fact escapes our attention only because of our continuous use of foreign words, the true meaning of which we tend to forget.

constitutes that important element without which correct understanding of the nature of rock-forming processes and a correspondingly correct determination of the rock sometimes prove impossible. Moreover, it is obvious that the petrographer must designate his rocks, certainly not on the basis of "abstract concepts" as implied by S. N. Ivanov, but on the basis of a study of the specific geologic environment which serves as no less a "realistic characteristic", than the mineralogical composition determined under the microscope.

As F. Yu. Levinson-Lessing once stated very appropriately: "the decisive word in petrogenetic problems always belongs to geology" [9].

From the aforesaid follows then the answer to the "baffling" question posed by S. N. Ivanov: what should one call a strongly altered basic effusive rock, the primary nature of which cannot be precisely determined? Of course, the inquirer believes that "porphyrite" is the sole acceptable name. But is it not clear that by giving an unidentified phenomenon an obscure name one can hardly claim to have defined it! Would it not be more scientifically correct to designate such a rock as "altered basic effusive", or even simply "altered effusive"? One should add here that if the petrographer does not entirely rely on the omnipotence of the microscope, and studies the rocks in the field, approaching them not as "fragments of stones", but as geologic objects, such "difficult" cases will actually prove to be not too numerous.

In order to exhaust the list of questions posed by S. N. Ivanov, it remains to refer to t the problem of the nomenclature of effusive rocks in geologic mapping. S. N. Ivanov writes: "I would like to hear Ye. K. Ustinov's explanation as to the precise nature of the confusion arising from the classification of rocks of volcanic origin into cenotypal and paleotypal. Why, for example, should a geologic map showing andesites and andesitic porphyrites become more legible and valuable if, on the basis of the preserved remnants of primary features, we referred to andesitic porphyrites simply as andesites?"

First of all, it is obviously wrong to call altered andesites "simply andesites" and no one actually suggests this. It is better to call them "altered andesites" (chloritized, carbonatized, sulfidized, etc.). This corresponds more closely to the nature of the rock and conveys more accurately the meaning of the term. Moreover, one should not speak only of andesites, but also of many other rocks, for which no designations are available in the scale of paleotypal varieties and which, therefore, are never identified in geologic surveys in the areas where ancient volcanic formations occur. Is it possible to conclude, therefore, that in the Mesozoic or Paleozoic there was no extrusion of theolites, phonolites, trachyandesites, and so on, within the confines of the folded zones and platforms of the Soviet Union? Certainly not, but all of these effusives are comfortably camouflaged today under the all-leveling designation of "porphyrites", so convenient in its indefiniteness. If one is to add here that concealed under the mask of albitophyres and keratophyres one often finds strongly altered effusive rocks by no means of acidic, but rather of average, or even basic composition, then the picture of the serious distortion of the historical development of magmatic phenomena in the process of geologic mapping becomes evident. It seems hardly necessary to argue that the problem of the accurate reconstruction of the evolution of volcanism and the volcanic rock compositions also has practical importance in addition to its scientific significance.

In protesting the proposal for a single nomenclature of effusive rocks, S. N. Ivanov refers to his experience gained during work in the Ural areas where there are widespread occurrences of paleotypal effusives. It is important to note that support for this suggestion comes from petrographers who were also engaged in mapping the older volcanic complexes in the Urals, the Caucasus, the Altay, and the Far East. Thus, S. N. Ivanov's experience is in direct opposition with the experiences of T. V. Dianova, N. D. Zlenko, M. A. Tarkhova, T. Ya. Goncharova, and I. M. Speranskaya.

T. Ya. Goncharova writes, in particular: "Despite a prolonged study of the old, primarily Paleozoic, strongly altered volcanic formations containing chalcopyritic mineralization in the Caucasus, the Altay, and partly in the Urals, we failed to come to a conclusion, like S. N. Ivanov, concerning the great confusion which would ensue should the paleotypal rock designations in the geological maps of regions containing predominantly effusive formations be replaced by cenotypal designations as suggested by Ye. K. Ustiyev. On the contrary, we believe that the maps can only gain thereby and be of greater value, provided of course, that definite conditions are observed, that these changes are not entirely left to the "discretion of the authors of individual maps" (S. N. Ivanov) and that they are made after a detailed and considered petrographic study of the effusive rocks"

Finally, still one more and last detail. S. N. Ivanov has several times underlined the negative features of a single nomenclature of effusives, calling it "Anglo-American", and opposed to it, the advantages of a dual nomenclature, to which he refers as the "domestic" system. I have written quite plainly that a single nomenclature for effusives is used by many geologists and

petrographers of Europe and the "countries of the Pacific belt", which, as is well known also includes China and Japan, Indonesia and Vietnam, and scores ofother nations which, by no stretch of imagination, could be called "Anglo-American". As to the epithet "domestic" with respect to the dual nomenclature, it might have been considered appropriate had S. N. Ivanov been a native of Leipzig or Heidelberg, where F. Zirkel and G. Rosenbusch, the main architects of dual nomenclature principles, actually lived and worked.

In conclusion, it is well to mention the definite good that may have resulted from this discussion. First of all, it has permitted the supporters of a single nomenclature for effusives to delineate clearly their positions and to reveal the weak points of its opponents. Furthermore, it has clearly evidenced the growing dissatisfaction among petrographers with the dual nomenclature system, which has begun to threaten the progress of field and theoretical petrography. One would think that the argumentation of the defenders of the dual nomenclature contributes more than anything else to its gradual disappearance. Its hundredth anniversary which is due within a short time will, apparently, also be its last.

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# ON A BOOK BY G.M. ZARIDZE AND N.F. TATRISHVILI "MAGMATISM IN GEORGIA AND ASSOCIATED ORE FORMATIONS"[1]

by
A. P. Lebedev

The book being reviewed may, to a certain extent, be considered an expansion of the composite, generalized studies on magmatism in Georgia published earlier by the same authors, or by one of them (G. M. Zaridze) [1, 2]. A characteristic mainly of the young effusive and intrusive magmatism in Georgia was given in the first study [1]. The second sheds some light on the magmatic formations of predominantly Paleozoic age [2]. The new summary covers both the first and the second groups of rocks.

There is a dual purpose in compiling extensive review studies on the petrography of individual major provinces such as the Georgian SSR. On the one hand, the object is to provide reference material where the reader can find the required information on all formations and rocks occurring in this region, along with the newest data on its petrography and geology. On the other hand, a general survey of materials on different forms of magmatic manifestations in a definite major province enables the authors of such a survey to make a certain critical analysis of the material from the standpoint of this or that petrological concept. It is deemed useful, therefore, to review this work with due consideration of these positions.

In the descriptive part the material in this study may be subdivided into two sections: 1) the old (Pre-Mesozoic) formations, and 2) the recent formations. Far more attention is devoted to the former, about three-quarters of the descriptive part in the book being devoted to them. Here one finds a description of rocks occurring in the Dzirul'skiy, Khramskiy, and other mountain massifs. These descriptions provide a detailed description of separate bodies and their sections, of individu types of rocks, their contacts and hydrotherma products, etc. The description is very detailed, sometimes excessively burdened with unnecessary particulars. One of the shortcomings of this section (as well as of the entir descriptive part) is the isolation of the recorded chemical analyses and quantitative estimates from the specific descriptions of the rocks. All of these analyses are given without "an address", without precise reference to locations, often in a generalized form. This, of course, considerably reduces their value to the reader for purposes of comparison, or as reference material. The absence of schematic charts showing distribution, sampling locations, etc., also must be considered as a defect. All this results occasionally in too much generalization and isolation of the descriptions from the actual environment.

The second group covers Meso-Cenozoic formations. It includes the "neointrusions", well known in the petrographic literature on the Caucasus, of acidic and average rocks, the Jurassic volcanic rocks of Racha, Southern Osetiya, Khevsuretiya, Kakhetiya, and Souther Georgia, the complex of young effusive formations of the Kazbek, and other volcanic centers This group of formations was described in G. M. Zaridze's summary of 1947 [1] referred to above. In contrast to this summary, the descriptions given here are in an extremely concise, often almost synoptical, form. A characteristic feature of this part of the book, which, incidentally, distinguishes it from the first ("pre-Mesozoic") part, is the lack of uniformity in the depiction of individual areas, imparting to the entire section and eclectic character and leaving an impression of incompleteness. The selection of individual sections, bodies, rocks, and entire formations for more detailed treatment appears to be made at random. Some of the descriptions are overly detailed, others are presented synoptically, and a few features are overlooke altogether. In arranging and compiling this

[1] O knige G. M. Zaridze i N. F. Tatrishvili "Magmatizm gruzii i svyazannyye s nim rudoobrazovaniya". pp. 114 - 116.

section the authors, we feel, should have followed the course of a more profound and generalized characterization of individual groups or formations, bearing in mind that more detailed factual material has already been presented with adequate completeness in the well-known surveys of Georgia prepared by G. S. Dzotsenidze, N. P. Skhirtladze, D. S. Belyankin, and V. P. Petrov. In this manner, generalized characteristics would have made it possible to throw, in a more systematic way, a more even light on this rich and diversified material.

The positive features, which favorably distinguish these descriptions from G. M. Zaridze's work published in 1947, is the method of region-by-region treatment of materials adopted in this study which facilitates its general use.

In summing up the characteristics of the book's descriptive part (Chapters 3 to 5), one should say that on the whole, in spite of the mentioned shortcomings, it still gives a fairly complete idea of the principal magmatic and metamorphic complexes in Georgia. In a new edition of this book is prepared, the authors would do well to eliminate the mentioned shortcomings (absence of schematic charts and adequate records on chemical analyses, etc.).

In the conclusive chapters of the book, which present an independent interest, the authors attempt to analyse the genetic problems of certain magmatic formations in Georgia and their metallogeny, from a definite viewpoint.

Basically, the petrogenetic deductions of the authors are related to the granitoids in the old and recent formations and to acidic effusives. They relate the origin of all intrusive acidic formations to the processes of silica, potassium, and sodium replacement. In their opinion, the granitoids appeared as a result of the transformation of the old country rocks (metamorphic and sedimentary) and the old basic rocks: gabbro and amphibolites (in the Dzirul'skiy massif). The acidic effusives, on the other hand, originated from basic magma contaminated by country-rock materials. The authors, apparently, totally discount the existence of intrusive or plutonic acidic magma. This point of view stands, thus, in contradiction to prevalent ideas on the genesis of the Caucasian granitoids.

What factual material then leads the authors to such conclusions? On the whole, this is material accumulated by observations carried out in the zones of mineralization and microclinization in the deeply eroded massifs constituting the remnants of the old crystalline basement (Dzirul'skiy mountain massif, the zone of crystalline schists in the Great Caucasus). It is true that in these regions one can observe pretty clearly the workings of the processes of metasomatic replacement of genisses and schists by quartz and feldspathic injections accompanied by the formation of porphroblastic microcline, petritization, albitization, silification, and other phenomena. Although some of these manifestations may, possibly, be associated with other processes (in particular, with metamorphic differentiation), nevertheless, it is really difficult to deny the great role played here by metasomatic replacement, and the authors are perfectly correct in calling the attention of petrographers to these phenomena. One can also agree with a few interesting considerations formulated in the same chapter with respect to the genesis of the accessory minerals of certain types of granitoids. The role of metasomatic processes in their formation is reflected very clearly in some places (apatite, sphene, and less distinctly with regard to zircon and orthite). Indications of metasomatic growth of the accessory minerals can, indeed, be traced also in some basic rocks, for example, in the Siberian traps.

Thus, the authors are perfectly right when they put strong emphasis on the great petrogenetic significance of alkaline and siliceous metasomatic processes in the described cases. In drawing attention to this aspect of granitoid petrogenesis in Georgia, and in providing a number of conclusive examples to this effect, the authors, no doubt, have rendered considerable service.

While recognizing along with them the great importance of the processes of metasomatic granitization in the formation of certain types of old granitoids in Georgia, one still cannot refrain from saying that the theory advanced by them that all granitoid intrusions in the Caucasus were formed exclusively in this manner, seems to be hardly acceptable, particularly when this concerns Post Jurassic intrusions. This theory fails to provide a satisfactory explanation for a considerable number of facts related to specific intrusions. Here are a few of these facts, 1) the obvious signs of high-temperature contact action produced by acid intrusions on the country rocks and followed by the formation of high-temperature hornfels (for example, in Teplinsk, Kazbek, and other neointrusions); 2) the shape of the intrusive bodies and the peculiarities of their internal structure point to the autonomous character of their development and to the phenomena of magmatic flow; 3) the sharply discordant, cross-cutting, positioning of the individual intrusive bodies with respect to the enclosing rocks; 4) a tendency toward a more uniform composition observable in major intrusions, and assimilation of xenoliths, 5) the petrochemical and (in a broader sense) the general geochemical characteristics of

individual intrusions and intrusive complexes (as described, for instance, in G. D. Afanasyev's works on the Greater Caucasus); 6) the multi-mineral composition of granitoids, which, according to D. S. Korzhinskiy, is at variance with their metasomatic genesis (the explanations furnished by the authors in this respect do not sufficiently clarify the question).

To accept the theory of metasomatic granitization on so large a scale as suggested by the authors, i. e. for the explanation of the formation of all granitoid intrusions (and not only for the rocks occurring in the old magmatic and injection zones), one must find answers to many new questions. First of all, that concerning the reasons for the selective character of metasomatism, which, in some cases, is of potassic, and in other cases of sodic, or combined type. Are the relations between them determined by tectonic factors, by the depth of intrusive body formation, by temperature, the composition of wall rocks, or by some factors — all these problems remain essentially unsolved by the authors. Yet, without solving them, it is impossible to answer the basic problems of petrology and metallogeny in the area under review. One should also note the lack of clarity in the authors' views on the nature of the granitizing emanations themselves. In certain instances they seem to approximate closely to the views held by V.S. Koptev-Dvornikov relative to the existence of "alaskitic" or "leucocratic" magma (p. 201), but in other cases they speak of "solutions consisting of silicium, potassium, and sodium" (p. 214).

In analyzing the problems concerning the relationship between endogenic mineralization and magmatism (chapter 7) the authors, along with the theory of the plutonic origin of ore elements, also recognize the role of processes causing the extraction of ore elements from the country rocks, and their subsequent concentration. It is possible to agree that thismethod of ore-substance accumulation (still insufficiently studied on specific examples) actually may have had considerable significance in the metallogeny of the Caucasus.

In considering the petrogenetic part of the book as a whole, we are inclined to acknowledge that the principal merit of the authors is that they were, possibly, the first authors dealing with the Caucasus to underline the great importance of the metasomatic processes in the genesis of the ancient-complex granitoids. However, the role of these processes in the genesis of acid intrusions in the upper structural stage appears to us to be exaggerated because of obvious under-estimation and insufficient appreciation of the processes unquestionably magmatic in character.

On the whole the reviewed book, no doubt, will contribute to a further expansion of our ideas ofmagmatism in Georgia. As to the original theoretical considerations presented in the book, they, in spite of their debatable nature, will stimulate a more profound study of the problem relative to the formation of granites not only in the Caucasus, but also in other regions.

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